FISCAL YEAR 1986 DEPARTMENT OF ENERGY AUTHORIZATION

(Basic Research Programs)

HEARING

BEFORE THE

SUBCOMMITTEE ON
ENERGY DEVELOPMENT AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

NINETY-NINTH CONGRESS

FIRST SESSION

FEBRUARY 28, 1985

[No. 28]

VOLUME II-A

Printed for the use of the
Committee on Science and Technology

U.S. GOVERNMENT PRINTING OFFICE
50-721 O WASHINGTON : 1985

COMMITTEE ON SCIENCE AND TECHNOLOGY

DON FUQUA, Florida, *Chairman*

ROBERT A. ROE, New Jersey
GEORGE E. BROWN, Jr., California
JAMES H. SCHEUER, New York
MARILYN LLOYD, Tennessee
TIMOTHY E. WIRTH, Colorado
DOUG WALGREN, Pennsylvania
DAN GLICKMAN, Kansas
ROBERT A. YOUNG, Missouri
HAROLD L. VOLKMER, Missouri
BILL NELSON, Florida
STAN LUNDINE, New York
RALPH M. HALL, Texas
DAVE McCURDY, Oklahoma
NORMAN Y. MINETA, California
MICHAEL A. ANDREWS, Texas
BUDDY MacKAY, Florida **
TIM VALENTINE, North Carolina
HARRY M. REID, Nevada
ROBERT G. TORRICELLI, New Jersey
FREDERICK C. BOUCHER, Virginia
TERRY BRUCE, Illinois
RICHARD H. STALLINGS, Idaho
BART GORDON, Tennessee
JAMES A. TRAFICANT, Jr., Ohio

MANUEL LUJAN, Jr., New Mexico *
ROBERT S. WALKER, Pennsylvania
F. JAMES SENSENBRENNER, Jr., Wisconsin
CLAUDINE SCHNEIDER, Rhode Island
SHERWOOD L. BOEHLERT, New York
TOM LEWIS, Florida
DON RITTER, Pennsylvania
SID W. MORRISON, Washington
RON PACKARD, California
JAN MEYERS, Kansas
ROBERT C. SMITH, New Hampshire
PAUL B. HENRY, Michigan
HARRIS W. FAWELL, Illinois
WILLIAM W. COBEY, Jr., North Carolina
JOE BARTON, Texas
D. FRENCH SLAUGHTER, Jr., Virginia
DAVID S. MONSON, Utah

Harold P. Hanson, *Executive Director*
Robert C. Ketcham, *General Counsel*
Regina A. Davis, *Chief Clerk*
Joyce Gross Freiwald, *Republican Staff Director*

Subcommittee on Energy Development and Applications

DON FUQUA, Florida, *Chairman*

ROBERT A. ROE, New Jersey
RALPH M. HALL, Texas
FREDERICK C. BOUCHER, Virginia
TERRY BRUCE, Illinois
JAMES A. TRAFICANT, Jr., Ohio
DOUG WALGREN, Pennsylvania
ROBERT A. YOUNG, Missouri
DAVE McCURDY, Oklahoma
RICHARD H. STALLINGS, Idaho
GEORGE E. BROWN, Jr., California

F. JAMES SENSENBRENNER, Jr., Wisconsin
CLAUDINE SCHNEIDER, Rhode Island
RON PACKARD, California
HARRIS W. FAWELL, Illinois
WILLIAM W. COBEY, Jr., North Carolina
JOE BARTON, Texas
D. FRENCH SLAUGHTER, Jr., Virginia

William T. Harvey, Jr., *Staff Director*
Harlan L. Watson, *Science Consultant*
William J. Gordon, *Republican Technical Consultant*
R. Thomas Weimer, *Republican Energy Coordinator*

---

*Ranking Republican Member.
**Serving on Committee on the Budget for 99th Congress.

CONTENTS

VOLUME II-A

WITNESSES

February 28, 1985: Page

Dr. Alvin W. Trivelpiece, Director, Office of Energy Research, U.S. Department of Energy, Washington, DC, accompanied by Dr. James E. Leiss, Associate Director, Office of High Energy and Nuclear Physics, and Dr. Donald K. Stevens, Acting Associate Director, Office of Basic Energy Sciences 3
    Prepared statement 12
    Discussion 74
    Questions and answers for the record 101
    Supporting research and technical analysis 101
        Basic energy sciences 101
            General 101
            Materials sciences 115
            Applied mathematical sciences 116
            Advanced energy projects 117
            BES construction 117
                Kansas State University Ion Collision Physics Facility (Project 85-ER-403) 117
                Columbia University National Center for Chemical Research (Project 84-ER-115) 119
                Catholic University of America Vitreous State Laboratory (Project 84-ER-114) 121
        Energy research analysis 122
        University research instrumentation 123
        University research support 124
        Advisory and oversight program direction 126
        Multiprogram laboratories facilities support 127
        General construction 131
    High energy physics 133
        General 133
        Superconducting super collider [SSC] 142
        Construction 144
            General plant projects (Project No. 86-R-103) 144
            Tevatron I (Project No. 81-E-218) 146
            Tevatron II (Project No. 82-E-206) 147
            SLAC linear collider (Project 84-ER-133) 148
    Nuclear Physics 150
        General 150
        Continuous Electron Beam Accelerator Facility [CEBAF] 158
        Construction 164
            Tandem/AGS heavy ion transfer line (Project 84-R-123) 164
            University accelerator upgrade at the University of Washington and Yale University (Project 84-ER-110) 164
    Minority Questions 165

PANEL 1: NEW RESEARCH OPPORTUNITIES

Dr. George C. Pimentel, chairman, National Research Council's Committee to Survey the Chemical Sciences, professor of chemistry, University of California, Berkeley, CA 169
    Prepared statement 173

Page
Dr. Daniel Kleppner, professor of physics, department of physics and research laboratory of electronics, Massachusetts Institute of Technology, Cambridge, MA 177
  Prepared statement 180
    Research briefings 1984: Report of the research briefing panel on selected opportunities in physics 185
    Daniel Kleppner, "Research in Small Groups," *Physics Today*, March 1985, vol. 38, No. 3, pages 78-85 197
Dr. Frederick Seitz, president emeritus, The Rockefeller University, New York, NY 205
  Prepared statement 208
  Panel 1 discussion 220
  Questions and answers for the record:
    Professor Pimentel 228
    Professor Kleppner 229
    Dr. Seitz 232

PANEL 2: MULTIPROGRAM LABORATORY DIRECTORS

Dr. Alan Schriesheim, director, Argonne National Laboratory, Argonne, IL 234
  Prepared statement 238
Dr. David A. Shirley, director, Lawrence Berkeley Laboratory, Berkeley, CA 245
  Prepared statement 249
Dr. Herman Postma, director, Oak Ridge National Laboratory, Oak Ridge, TN 263
  Prepared statement 267
    Nicholas Basta, "Ion-Beam Implantation," *High Technology*, February 1985, pages 57-61 277
  Panel 2 discussion 281
  Questions and answers for the record:
    Dr. Schriesheim 283
    Dr. Shirley 309
    Dr. Postma 315

PANEL 3: HIGH ENERGY AND NUCLEAR PHYSICS

Dr. John P. Schiffer, Chairman, Department of Energy/National Science Foundation Nuclear Science Advisory Committee, Argonne National Laboratory, Argonne, IL 322
  Prepared statement 342
    "Report of the NSAC Ad Hoc Subcommittee on a 4 GeV Electron Accelerator for Nuclear Physics," DOE/NSF Nuclear Sciences Advisory Committee, September 27, 1984 357
    "Review of the 1983 Long Range Plan for Nuclear Science," DOE/NSF Nuclear Sciences Advisory Committee, November 1984 367
Dr. Maury Tigner, director, Universities Research Association Superconducting Super Collider Central Design Group, Lawrence Berkeley Laboratory, Berkeley, CA 373
  Prepared statement 382
  Panel 3 discussion 401
  Questions and answers for the record:
    Dr. Schiffer 406
    Dr. Tigner 408

PANEL 4: HIGH ENERGY AND NUCLEAR PHYSICS LABORATORY DIRECTORS

Dr. Leon M. Lederman, director, Fermi National Accelerator Laboratory, Batavia, IL 412
  Prepared statement 416
Dr. Burton Richter, director, Stanford Linear Accelerator Laboratory, Stanford, CA 437
  Prepared statement 441
Dr. Nicholas P. Samios, Director, Brookhaven National Laboratory, Upton, NY 447
  Prepared statement 450
  Panel 4 discussion 460
  Questions and answers for the record:
    Dr. Lederman 463
    Dr. Richter 473
    Dr. Samios 475

Page
Appendix 1: Statement for the record by the energy committee of the National Association of State Universities & Land-Grant Colleges 485
Appendix 2: Additional materials for the record:
  "Materials Sciences Division Long Range Plan," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Division of Materials Sciences, Washington, DC, December 1984, DOE/ER-0212 489
  "Major Facilities for Materials Research and Related Disciplines," Major Materials Facilities Committee, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, National Academy of Sciences, Washington, DC, 1984 534
  "Review of the National Research Council Report 'Major Facilities for Materials Research and Related Disciplines,'" prepared by the Materials Ad Hoc Review Panel, a report of the Energy Research Advisory Board to the U.S. Department of Energy, Washington, DC, June 1985, DOE/S-0037 618
  "Cost Estimate for LEU Conversion and Standardization of University Research and Test Reactor Fuels," Office of Energy Research, U.S. Department of Energy, 1985 666
  "To the Heart of the Matter—The Superconducting Super Collider," Universities Research Association, March 1985 698
  "Superconducting Super Collider Siting Parameters Document: A Technical Advisory on SSC Site Criteria and Catalog of Site Information Needs," SSC Central Design Group, Universities Research Association, Lawrence Berkeley Laboratory, University of California, Berkeley, CA, June 15, 1985, SSC-15 737
  "Nuclear Physics Accelerator Facilities," U.S. Department of Energy, Office of Energy Research, Division of Nuclear Physics, Washington, DC, January 1985, DOE/ER-0216 791
  "DOE's Physics Accelerators: Their Costs and Benefits," report by the U.S. General Accounting Office, GAO/RCED-85-96, April 1, 1985 824
  Department of Energy fiscal year 1986 congressional budget request energy supply research and development, supporting research and technical analysis 923
    Program overview 924
    Basic energy sciences 926
      Construction project data sheets 954
    Energy research analysis 986
    University research support 991
    University research instrumentation 999
    Advisory and oversight program direction 1001
    Multiprogram laboratories facilities support 1004
      Construction project data sheets 1014
  Department of Energy fiscal year 1986 congressional budget request general science and research, volume 4 1073
    Appropriation language 1074
    Summary of estimates by major category 1075
    Program overview 1076
    High energy physics 1079
      Physics research 1088
      Facility operations 1091
      High energy technology 1102
      Construction project data sheets 1107
    Nuclear physics 1133
      Medium energy nuclear physics 1139
      Heavy ion nuclear physics 1141
      Low energy nuclear physics 1144
      Nuclear theory 1145
      Construction project data sheets 1150
    General Science Program direction 1157

VOLUME II-B

Appendix 3: Basic energy sciences research accomplishments and project summaries:

Page

"Office of Basic Energy Sciences 1984 Summary Report: A Summary of the Organization, Mission, and Activities of the Office of Basic Energy Sciences," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Washington, DC, DOE/ER-0146/1, November 1984 1

"Some Examples of Accomplishments Under the Basic Energy Sciences Program During 1984," February 1, 1985 30

"Materials Sciences Programs Fiscal Year 1984," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Division of Materials Sciences, Washington, DC, September 1984, DOE/ER-0143/2 53

"Summaries of Fiscal Year 1984 Research in the Chemical Sciences," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Division of Chemical Sciences, Washington, DC, September 1984, DOE/ER-0144/2 311

"Summaries of the Fiscal Year 1984 and Fiscal Year 1985 Applied Mathematical Sciences Research Program," U.S. Department of Energy, Office of Energy Research, Scientific Computing Staff, Applied Mathematical Sciences, Washington, DC, July 1985, DOE/ER-0240 437

"Summaries of Fiscal Year 1984 Engineering Research," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Division of Engineering and Geosciences, Washington, DC, December 1984, DOE/ER-0158/2 491

"Summaries of Physical Research in the Geosciences," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Division of Engineering, Mathematics & Geosciences, Washington, DC, September 1984, DOE/ER-0145/2 577

"Advanced Energy Projects Fiscal Year 1984 Research Summaries," U.S. Department of Energy, Division of Advanced Energy Projects, Office of Basic Energy Sciences, Washington, DC, October 1984, DOE/ER-0150/2. 736

"Annual Report and Summaries of Fiscal Year 1984 Activities Supported by the Division of Biological Energy Research," U.S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, Division of Biological Energy Research, Washington, DC, October 1984, DOE/ER-0147/2 771

Appendix 4: High energy physics research summaries:

"Summaries of Fiscal Year 1984 Research in High Energy Physics," U.S. Department of Energy, Office of Energy Research, Office of High Energy & Nuclear Physics, Division of High Energy Physics, Washington, DC, December 1984, DOE/ER-0210 837

1986 DEPARTMENT OF ENERGY AUTHORIZATION

THURSDAY, FEBRUARY 28, 1985

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Development and Applications,
Washington, DC.

The subcommittee met, pursuant to notice, at 10:04 a.m., in room 2325, Rayburn House Office Building, Hon. Don Fuqua (chairman of the subcommittee) presiding.

Present: Representatives Brown, Walgren, Boucher, Mineta, Stallings, Bruce, Sensenbrenner, Packard, Fawell, Barton, Cobey, and Slaughter.

Also present: Representative Carney.

Staff present: Harlan L. Watson, Ezra Heitowit, Bill Harvey, William Gordon, and Tom Weimer.

Mr. Fuqua. The subcommittee will be in order.

We begin today the first in a series of hearings to be held by the Subcommittee on Energy Development and Applications concerning the fiscal year 1986 authorization request for the Department of Energy's programs in basic research, conservation and renewable energy, and fossil energy.

Today we begin our consideration of the basic research programs in the Department of Energy for which the administration has requested over $1.16 billion. These programs include basic energy sciences, university research support and instrumentation, multiprogram general purpose facilities, and high energy and nuclear physics; and they support long-range frontier research performed at our national laboratories and universities.

The fiscal year 1986 request for programs under this subcommittee's jurisdiction is some $46 million, or about 3.5 percent, below the current year's appropriated levels.

While the current budget deficit climate may warrant a slowdown in the growth of funding for basic research, we also want to make sure that important new science opportunities relevant to the Department of Energy's mission will be supported to the extent possible.

Today, our leadoff witness will be Dr. Alvin Trivelpiece, Director of DOE's Office of Energy Research, to discuss the Department's fiscal year 1986 request. He will be accompanied by Dr. Don Stevens and also Dr. Jim Leiss.

Following the DOE witnesses we will hear from a number of distinguished academic and laboratory scientists on new research opportunities, as well as the status of nuclear physics research and the Superconducting Super Collider. We will also have two panels of laboratory directors who will give us their assessment of the impacts of the fiscal year 1986 budget request on their respective institutions.

Before we start, I want to apologize for any inconvenience caused those witnesses who had originally been scheduled to appear yesterday. I appreciate your juggling your schedules so you can be here today. We also have business on the House floor starting at 11 a.m., so I'm sure we'll have other interruptions during the process of the hearing.

Mr. **SENSENBRENNER**. Thank you, Mr. Chairman, for this opportunity to extend a welcome to Dr. Trivelpiece, the Director of DOE's Office of Energy Research, and to our distinguished panelists. I look forward to Dr. Trivelpiece's testimony on the research programs conducted by his office. These programs include high energy and nuclear physics, basic energy science, university support, and related activities. They support long-range basic research that provides the fundamental scientific and engineering base on which this country's future energy options will depend.

Furthermore, our Nation's lead in science and technology, which are at the core of our economic competitiveness, and the training of future scientists are served by a continuing aggressive program of basic research. The administration has proposed a small reduction for these programs in fiscal year 1986 by more or less freezing operating expenses, except for inflationary adjustments, and putting a hold on new construction projects. I believe the deficit problem confronting Congress warrants such a freeze of these DOE activities. However, I look forward to the testimony of our lab directors and scientists and their views on how this slowdown in R&D will impact the Federal labs and progress in the science community.

I thank you.

Mr. **FUQUA**. Thank you very much.

Dr. Trivelpiece, we'd be pleased to hear from you at this time.

[The biographical sketch of Dr. Trivelpiece follows:]

Dr. Alvin W. Trivelpiece was nominated by the President on July 8, 1981, and confirmed by the Senate on July 27, 1981, as Director of the Office of Energy Research, U.S. Department of Energy (DOE). In this position, Dr. Trivelpiece serves as technical adviser to the Secretary on the Department's energy research and development programs and is responsible for the multipurpose laboratories and energy education and training activities. In addition, he manages DOE's programs for basic energy research, health and environmental research, high energy and nuclear physics, and magnetic fusion.

Dr. Trivelpiece has extensive experience in the areas of plasma physics and fusion research. From 1978 until assuming his current position, Dr. Trivelpiece was Corporate Vice President of Science Applications, Inc., of La Jolla, California, primarily responsible for internal research programs relative to innovative technical developments. From 1976 to 1978, he was Vice President for Engineering and Research at Maxwell Laboratories, San Diego, California.

During the period 1973 to 1975, Dr. Trivelpiece served with the U.S. Atomic Energy Commission as Assistant Director for Research in the Division of Controlled Thermonuclear Research. Prior to joining the Federal Government, he was Professor of Physics at the University of Maryland, serving in that capacity from 1966 to 1976. From 1959 to 1966, he was a professor at the University of California at Berkeley in the Department of Electrical Engineering.

He received a B.S. degree from California Polytechnic State University in 1953, an M.S. degree in 1955, and a Ph.D. degree in 1958. Both advanced degrees were awarded by the California Institute of Technology.

The recipient of several honors and awards, Dr. Trivelpiece is listed in American Men and Women of Science, Who's Who in America, and Who's Who in the World. He holds several patents in the area of physics research and is the author and coauthor of over 100 technical reports and books. Dr. Trivelpiece is a member of numerous professional organizations and is a fellow of the American Physical Society, the Institute of Electronics and Electrical Engineers, and the American Association for the Advancement of Sciences. He has served as a consultant to various private associations and Government agencies and has lectured at conferences and universities throughout the United States and abroad.

Dr. Trivelpiece was born in Stockton, California. He is married and has three children.

STATEMENT OF DR. ALVIN W. TRIVELPIECE, DIRECTOR, OFFICE OF ENERGY RESEARCH, U.S. DEPARTMENT OF ENERGY, WASHINGTON, DC; ACCOMPANIED BY DR. DONALD K. STEVENS, ACTING ASSOCIATE DIRECTOR, OFFICE OF BASIC ENERGY SCIENCES; AND DR. JAMES E. LEISS, ASSOCIATE DIRECTOR, OFFICE OF HIGH ENERGY AND NUCLEAR PHYSICS

Dr. **Trivelpiece**. Mr. Chairman, members of the subcommittee, it's a pleasure to be here today. This is the fourth year that I've had the opportunity to appear before this committee, which just illustrates how fast time flies when you're having fun.

I know that time is short today, and each year as I've made these opening remarks you've indulged me a few minutes to make some generalized remarks. I'd like to do so again today.

I make no particular secret of my enthusiastic support for science and technology and the fact that I believe that it is one of the engines which drives our economy. There are many, many things in our gross national product today that owe their existence to pioneering research that was done not only by the Department of Energy but by other agencies of the Federal Government who support basic research. And to that extent, Mr. Chairman, I'd like to thank you for last year when you were gracious enough to include a letter to the editor that I had written to many journals in the Congressional Record. As you recall, that letter focused on the idea that those of us who earn a living at science and technology really should make an effort to try to see to it that those who do not, your constituents, appreciate the fact that everything that we eat, drive, fly, buy, and so on, has some of its origins in basic research that's been supported by the Federal Government in the past.

[The information follows:]

Department of Energy
Washington, D.C. 20585

JUN 12 1984

Mr. George Kotnick
President
American Society of
Mechanical Engineers
1825 K Street, NW
Suite 215
Washington, D.C. 20006

Dear Mr. Kotnick:

Enclosed is a copy of a "Letter to the Editor" for possible printing in an appropriate ASME Journal. I am sending this same letter to the presidents of other technical societies as well as to the President of the Chamber of Commerce and national presidents of several civic and service clubs.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

Enclosure

Identical letters sent to:

Dr. Richard Gowen
President, IEEE

Dr. Mildred Dresselhaus
President
American Physical Society

Dr. Warren D. Niederhauser
President
American Chemical Society

Dr. Joseph Hendrie
President
American Nuclear Society

Mr. William E. Skelton
President
Rotary International

Mr. John T. Roberts
President
Kiwanis International

President
US Jaycees

Dr. Anna Harrison
Presisent
American Association for the
Advancement of Science

Dr. John McLucas
President
American Institute of Aeronautics
and Astronautics
COMSAT Corp.

Mr. L. E. Steele
President
Federation of Materials Societies
Naval Research Laboratory

Dr. Hirsh Cohen
President
Society for Industrial and
Applied Mathematics

Department of Energy
Washington, D.C. 20585

LETTER TO THE EDITOR

Science and Technology Awareness Month

During the past three years, I have testified before several congressional committees on various aspects of some of the Department of Energy's (DOE's) science and technology programs. A recurrent theme of the questions asked by the members of these committees has been, "What are we getting for our money by supporting basic research?" In reply, I have used what I now call the "standard argument." I usually cite some of the Federally supported basic and applied research conducted ten or twenty years ago. I then point out how many of our present goods, services, products, health care benefits, etc. can be traced to that support. For DOE it is an impressive list that includes nuclear power, nuclear medicine, and radiation processing. It is clear that some substantial portion of our gross national product comes from this kind of activity. Unfortunately, this explanation is not particularly useful to a Representative or Senator seeking ways to explain to the nonscientist constituent why the present levels of government support for basic and applied research are essential for the future economic growth in certain technical areas where the United States must remain among the leaders. Without such support, we could easily lose our ability to compete internationally in these areas.

The importance of having members of Congress informed on this issue can't be underestimated. Those of us who testify help in the process of keeping them informed. But they are busy, and science and technology are not always their highest priority. For this reason, I believe that in the final analysis, it may be more important for a substantial number of our citizens to have a better appreciation of the fact that virtually everything that they eat, drive, fly, view, take, wear, etc. exists in its present form in part due to past Government support of basic and applied research. Industrial support of applied research and development is also essential to this process and needs to be encouraged. However, at the moment, I am more concerned with the Government role in the basic end of the activities.

I have a suggestion on how to improve this situation of public understanding of the role of science and technology in our lives. I believe that it is time for scientists and engineers to take more responsibility for explaining science and technology in ways the rest of our citizens can understand and appreciate. That is, we need to convince them that science and technology are important to our nation's future. How to accomplish this? Pamphlets, T.V, radio, and other media events help. Traveling lecturers who give excellent views of technical subjects in entertaining ways help. However, in my opinion there is no substitute for person-to-person contact between scientists and engineers and members of the rest of the community in which they live.

Therefore, I propose that October be designated "Science and Technology Awareness Month." What this means is that members of the ASME, SIAM, IEEE, APS, ANS, ACS, AAAS, AIAA, etc. volunteer to give a simple, jargon-free talk on what they do and why they believe it is important to our Nation. They should give these talks to their local chapter of the Jaycees, Rotary, Kiwanis, Lions, Chamber of Commerce, or any other appropriate civic or service organization. Far from being put off, I find that the public that I come in contact with is fascinated by science and technology and is willing to learn about them and the benefits they produce. It helps if things are put in terms that they understand and the explanation comes from a friend or neighbor.

My objective is to cause the greatest possible mixing of those who earn a living as scientists or engineers with those who do not. If this kind of interaction is to occur, it needs to be stimulated but need not be too highly organized. In my attempt to try to stimulate this activity, I am sending this same letter to several civic service clubs and booster organizations with the hope that they will contact the various local or national technical professional societies to make arrangements to have some of you talk to them. If you believe that a better informed public is important for the health of U.S. science and technology, then please volunteer to help make conditions better by talking to your local service club, high school PTA, or civic clubs. By the way, invite your mayor, councilman, representative, or senator. They might enjoy your talk and add some thoughts of their own. Since this is being suggested in the spirit of volunteerism, I will give a talk on DOE's basic research programs to the first service or civic club that invites me.

Alvin W. Trivelpiece
Director, Office of
Energy Research

FOR YOUR INFORMATION

Department of Energy
Washington, D.C. 20585

JUN 12 1984

Dr. Richard L. Lesher
President, Chamber of Commerce
of the United States
1615 H Street, N.W.
Washington, D.C. 20062

Dear Dr. Lesher:

Enclosed is a copy of a "Letter to the Editor" that I have sent to the presidents of several technical professional societies and civic service clubs. I have also discussed the idea expressed in the letters with Dr. Harvey Alter. I will follow-up with him to suggest that the Chamber take the lead and invite representatives of several of these organizations to form a steering committee to supply the small amount of guidance and coordination that might be needed to encourage this kind of volunteer effort. I believe that the Chamber is the most appropriate institution for many reasons. The main ones are the need not to have the appearance that a particular field of science or engineering is "pushing" its own area, and the need to have the "pull" for this activity come from the service and commerce organizations that should invite the speakers.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

Enclosure

cc: Harvey Alter

Dr. **Trivelpiece**. When I wrote that letter my expectations were rather modest, and that was that I hoped a few of my colleagues would take the opportunity to talk at service clubs during the month of October, and call October "Science and Technology Awareness Month." And in that letter I suggested I would be willing to talk to the first service club that invited me. It was somewhat with apprehension that I made that offer; fortunately, the Annandale, VA Rotary Club invited me and I quickly accepted their invitation. It wasn't until after I'd accepted that invitation that I realized perhaps I'd been a bit hasty, because the Heidelberg, Germany Lions Club also invited me. It was with regret that I declined their kind invitation. [Laughter.]

An event that I suspect has occurred to you and your colleagues, your children—if you have them—on one occasion or another has brought a rock and said, "Hey, Dad, look at the rock. Isn't this interesting?" That event has probably occurred thousands and thousands of times over the human experience.

There was an event that occurred a few years ago in which that same circumstance occurred, and this time it was probably a little bit different in that the individual who was giving the rock to his father was Walter Alvarez, the geophysicist, and the father is Luis Alvarez, Nobel Prize winner, who is at the Lawrence Berkeley Laboratory. The fact that he tossed his father this rock caused a great collection of things to be set in motion. One of those was that he pointed out to his father that this rock had three layers in it, that in the layer below the middle layer, there were dinosaurs; above this layer, which is approximately a centimeter thick, there were no dinosaurs.

Now, that might have ended it, except that Luis Alvarez is an individual with a consuming curiosity, and he also had available to him certain facilities that might not otherwise be available; that is, a laboratory that is capable of using neutron activation to measure incredibly small parts per billion of trace elements. And the investigation of that rock revealed that in that clay layer that separated the period when there were dinosaurs and there weren't dinosaurs, there was a higher concentration of iridium. That concentration of iridium and the subsequent theories that have grown from this have revealed that perhaps our Sun is not a sole star but is, in fact, part of a binary star system; and there are lots of young scientists and astronomers and astrophysicists out there looking for that particular binary star.

Why is that important? How does it apply to things today? Dinosaurs disappeared 65 million years ago, and the fact that they disappeared and the research that has been done as a result of the Alvarez's efforts, and others, has changed a little bit how we think about evolution. It's changed a great deal in the way of science and thought concerning where the world is going and how it might get there. The nuclear winter has grown out of that.

Is it excellent research? I think it is excellent research, and the way you tell it's excellent research is that it has attracted an unusually large collection of peers to work in the field, and other young scientists are flocking to it. Many of them are out there trying to find this so-called "companion star" to our Sun. It's been named a "nemesis" star.

Well, the opportunity for Dr. Alvarez to do this kind of research is in part available because of the facilities the Department has put in, and we have supported people like him who are excellent in their ability to do research over a large number of years. That continuity and stability and capability and facilities all go together in a fabric that is a little bit difficult to separate.

Today, as Mr. Sensenbrenner indicated, we are coming in with budgets that are a little bit constrained, and the requested budgets do represent a compromise between the need and the desire to continue the kind of excellent research and the commitment to science and technology both that the Department has made and certainly that the President has indicated his strong support for. We're trying to preserve the excellent people and maintain the core of these programs during this period of budgetary constraint. We strove for balance and we've tried to maintain the excellent parts of the basic research.

I am bombarded, probably, as much as you are by the thought that we're not doing enough of this or not doing enough of that, and that's probably always true. But the question is, How well are we doing on the front, which I would call the excellence front? Does the Department really support excellent research? Just this last year we had the good fortune to award Dr. Bob Wilson the Fermi Award through the Department of Energy. And I know that in a hearing before the Joint Committee for Atomic Energy, about 1968 or 1969, Dr. Wilson was asked something to the effect of, "Well, will this research help us defend America?" And paraphrasing his reply, which I didn't get the direct quote for, it was that the fact that we do this kind of research is what makes America worth defending. Of course, today he might have a slightly different answer to that question because one of the Strategic Defense Initiative elements owes its existence to activities that did grow out of high energy physics research some time ago.

In addition to Dr. Wilson receiving the Fermi Award, Dr. Vendreyas received the Fermi Award. We had 5 Lawrence Award winners, and just recently in this last 2 weeks, the President has awarded the Medal of Science to a number of outstanding individuals, some of whom are in the room, and has awarded the Medal of Technology to other individuals. The Science Digest listed 100 of the smartest people in the United States, and I'm pleased to point out that something in excess of a third of them are directly supported by the Department of Energy and the programs that we're talking about here today.

As we review the programs, and in the natural course of things, it always tends to focus a little bit on the critical aspects, the things that we're perhaps doing wrong—are we doing things that aren't relevant, and so on. I'd ask you, in thinking about this year's hearing activities and so on, that you give some thought to asking the questions that regard excellence—not to focus so much on the deficiencies, but on the excellence. And to that extent, I know that you have a collection of outstanding individuals who will testify subsequent to this opening hearing, but you have invited in the Nobel Prize winners and to some extent we use Nobel Prize winners as an index of how well we're doing in some of these areas.

I would like to suggest that perhaps you invite in some of the other winners, like the winners of the Medal of Science, Technology, Fermi winners, Lawrence winners, and ask them what it is about our system that gives them the opportunity to do the kind of excellent research that they do rather than focusing, perhaps, so intently on the relevance.

In the past at these hearings I've started things off with a slide show on all the facilities. I realize that time is short and that it would probably be inappropriate today. For the new members we have provided pictures of some of the facilities. I make the offer I traditionally make; I would be glad to meet with them privately and explain any of these facilities at any time. I'm sure you have many questions.

Mr. Chairman, that concludes my opening remarks. I'd be happy to answer any questions you might have.

[The prepared statement of Dr. Trivelpiece follows:]

STATEMENT OF ALVIN W. TRIVELPIECE, DIRECTOR OF ENERGY RESEARCH, DEPARTMENT OF ENERGY

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss the FY 1986 budget request for the Energy Research (ER) programs under the Supporting Research and Technical Analysis budget activity within the Energy Supply R&D appropriation. They include: Basic Energy Sciences, Energy Research Analysis, University Research Support, University Research Instrumentation, and Multiprogram Laboratories Facilities Support. The FY 1986 budget request totals $481.3 million for these programs. They are reflected in Table 1 which shows the total ER budget request for FY 1986. I would like to discuss each of these programs briefly, beginning with Basic Energy Sciences (BES).

Achievement of the Nation's economic goals will depend in large part on knowledge produced by a strong, broad national science capability--a capability to which the Basic Energy Sciences program contributes. Experience indicates that investment in human capital is no less important to the economy than machine tools and industrial plants and that the advance of scientific knowledge is a significant factor in the growth in productivity of the United States.

The support of long-range basic research, such as that funded by the Basic Energy Sciences program, is the responsibility of the Government. An appropriate Federal role for mission agencies, including the Department of Energy (DOE), is to support the foundation of basic science as well as mission-oriented applied research in appropriate disciplines. The FY 1986 budget request for the BES program recognizes that, even in a year of challenging and necessary budget constraints, well-chosen basic research will continue to contribute to the Nation's economic growth, well-being and national defense.

Table 1
Office of Energy Research
Summary by Program
($ in millions)
Budget Authority

	FY 1985 Estimate	FY 1986 Request
General Science & Research		
High Energy Physics	$545.6	$510.1
Nuclear Physics	182.8	172.9
General Science Program Direction	2.2	2.4
Subtotal	$730.6	$685.4
Energy Supply - R&D		
Basic Energy Sciences	$422.6	$409.8
Magnetic Fusion Energy	437.0	390.0
Biological & Environmental Research	190.5	186.3
Energy Research Analysis	3.0	2.7
University Research Support	11.2	9.7
University Research Instrumentation	5.0	4.5
Multiprogram Laboratories Facilities Support	33.2	51.2
Advisory & Oversight Program Direction	2.8	2.9
Policy and Management	0.5	0.5
Subtotal	$1,105.8	$1,057.6
Total ER	$1,836.4	$1,743.0

The goal of the Basic Energy Sciences program is to develop basic scientific and engineering knowledge that can be used by the Government and the private sector to develop new concepts, products, materials and processes. Although the principal focus of the BES program relates to energy development and use, a number of other important national goals are also supported. U.S. leadership in science and technology, economic growth and training for tomorrow's scientists are all beneficiaries of properly conceived programs of basic research. While contributions from basic research cannot always be identified immediately or directly, the knowledge that flows from this research forms the foundation on which new ideas and concepts can build in each of these areas.

The BES program annually supports approximately 1200 individual research projects in the physical, biological and mathematical sciences. These projects are selected on the basis of scientific excellence, relevance to BES' long-term goals and their contribution toward a balanced research program. This research is carried out largely by scientists at universities and national laboratories across the country.

An important benefit that results from supporting university researchers is the technology transfer that occurs when graduate students carry their new knowledge into the private sector after completing their studies. In addition to universities and laboratories, BES also maintains ties with industry through a variety of mechanisms. These include participation in workshops and the use by industry of the specialized research facilities supported by BES.

During the past year, BES research was conducted in seven areas: materials sciences; chemical sciences; nuclear sciences; mathematical; engineering and geosciences; biological sciences; and advanced energy projects. The impact of research results from over 1200 projects cannot easily be conveyed, not only because of their volume, but also because their ultimate importance may not be evident at first. The following recent examples of research results do, however, provide insight into the diversity and scope of the BES program.

These accomplishments include:

o Development of a new high-temperature, oxidation-resistant material (nickel aluminide) that can be produced by conventional methods and is better than existing super alloys for use where long-term, high-temperature service is required, such as in heat engines. The potential of this aluminide has already been recognized by an IR-100 award as well as industrial interest in producing this material.

o Development of a novel processing method that permits machining of materials to a dimension 1000 times smaller than can be accomplished commercially today. One potential application of this method is the development of computer memories with storage densities 1 million times greater than is presently possible. New applications, such as the one just cited, will require new manufacturing concepts rather than refinement of current ones.

- o Discovery of a new catalytic system for the direct conversion of carbon monoxide and water to methanol. This new catalyst makes it possible to make the conversion using water rather than the more expensive hydrogen and at pressures and temperatures much lower than current practice allows.
- o Development of improved solid state electronic devices to operate at higher temperatures, thus paving the way to important advances in measurement methods and process control in hostile environments.
- o Demonstration of a new source of electromagnetic radiation, known as the free electron laser, at conversion efficiencies and power levels which make the laser a candidate source for numerous applications, including extremely powerful accelerators.

While it is not possible to say which of the above research accomplishments might have major strategic or economic importance in the future, it is important to realize that today's high technology industry is based on similar research carried out in the past.

To illustrate my point, some 25 years ago the materials program supported the initial research on metallic glasses. These glassy metals have an atomic structure that is different from the metals with which we are familiar. We now know that metallic glasses are useful in magnetic applications because they can be magnetized and demagnetized with less energy loss than can ordinary structured metals. We also know that they are potentially the strongest, most corrosion-resistant material known and that they are economical to manufacture because the production process uses less energy than consumed by conventional processes.

As a result of that original research and subsequent basic and developmental research done by industry and universities, glassy metals have made a significant impact in the commercial areas of communication and lighting; for example, they are being used in the recording and playback heads of tape recorders and in the starting circuits in fluorescent lights. Research in the private sector continues on production techniques for glassy metals. One potential additional use might be the substitution of glassy metals for steel in electric power transformers. Losses in magnetic energy in these transformers amount to more than $600 million a year, most of which might be saved with the use of glassy metals.

As is illustrated by this example, the results of basic research can take as long as 10 to 20 years before there are commercial applications. Thus, I believe that it is fair to say that the funding for research in the basic sciences can be considered crucial for technological progress in the future.

This kind of research progress is made possible, in part, by the large state-of-the-art facilities that are supported by the BES program. These facilities are not only an integral part of the program; they also serve the scientific community. Industry, university and government researchers have access to these facilities for promising research projects. These facilities are available at no cost to the user if the project is of high technical merit, is of interest to DOE and cannot be carried out without access to the facility. In addition, the significant results are published and made available to the R&D community. If the research requires the use of the facility but is of a proprietary nature, a user fee is charged. This combination of laboratory, university and industry researchers working side by side is extremely beneficial. The government gains when researchers supported by our program interact with their counterparts in the private sector. We also benefit from the trained scientists and unique instrumentation and equipment that are provided at no cost to the Department by the companies that conduct research at our facilities. Both industry and the university communities gain by having access to some of the most advanced facilities in the world.

Several state-of-the-art facilities are in operation. Each promises to open whole new areas of research opportunities. These facilities include: the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory; the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory; the 1.5 MeV High Voltage Electron Microscope and the Atomic Resolution Microscope (ARM) located at Lawrence Berkeley Laboratory's National Center for Electron Microscopy; and the Combustion Research Facility (CRF) at Sandia Livermore. A list of BES user facilities is contained in Table 2.

Table 2
Basic Energy Sciences Facilities

High Flux Beam Reactor (HFBR) - Brookhaven National Laboratory

National Synchrotron Light Source (NSLS) - Brookhaven National Laboratory

Intense Pulsed Neutron Source (IPNS) - Argonne National Laboratory

High Voltage Electron Microscope-Tandem Facility - Argonne National Laboratory

Oak Ridge Electron Linear Accelerator (ORELA) - Oak Ridge National Laboratory

High Flux Isotope Reactor (HFIR) - Oak Ridge National Laboratory

Combustion Research Facility (CRF) - Sandia National Laboratories, Livermore

National Center for Electron Microscopy - Lawrence Berkeley National Laboratory

Stanford Synchrotron Radiation Laboratory (SSRL) - Stanford University

Spallation Neutron Research Facility (SNR) - Los Alamos National Laboratory

BES FY 1986 BUDGET REQUEST

The FY 1986 budget request for the BES program is $409.8 million, which consists of $343.2 million in Operating Expenses, $30.5 million in Capital Equipment and $36.1 million in Construction funds (Table 3).

This request supports the core program for each of the research areas at the FY 1985 level, with modest increases in the materials and nuclear sciences areas for major user facility operations. The requested increase of $5.4 million in Materials Sciences and $3.0 million in Nuclear Sciences will cover increased costs related to power, fuel, essential operating personnel as well as safeguards and safety requirements.

Of the total FY 1986 Operating Expenses request of $343.2 million, approximately 30% will be spent to operate and carry out research at the major BES facilities. As I noted earlier, these facilities are used not only by the Department, but also by other Federal agencies, by industry and by university researchers. They represent an investment in the Nation's long-term research and technological future. The budget request will ensure continued operation and access to these facilities in FY 1986.

The FY 1986 budget also would continue support for promising research that we believe will have a significant impact on energy. Three items in the request exemplify the type and diversity of research with such potential.

Table 3
Basic Energy Sciences
Budget Authority
($ in millions)

	FY 1985 Estimate	FY 1986 Request
Operating Expenses		
Materials Sciences	$133.0	$138.5
Chemical Sciences	79.5	79.5
Nuclear Sciences	40.3	43.3
Applied Mathematical Sciences	35.1	28.0
Engineering and Geosciences	26.7	26.7
Advanced Energy Projects	10.6	10.6
Biological Energy Research	12.5	12.5
Program Direction	3.8	4.1
Subtotal	$341.5	$343.2
Capital Equipment	31.1	30.5
Construction	50.0	36.1
Total Basic Energy Sciences	$422.6	$409.8

These are advanced materials research, combustion research and enhanced computational research and computer access. Let me first discuss advanced materials research.

The FY 1986 budget request will continue support for the materials initiative that began in FY 1984. That activity currently consists of a Center for Advanced Materials at Lawrence Berkeley Laboratory, improvements at the Stanford Synchrotron Radiation Laboratory and expanded activities at Brookhaven National Laboratory's National Synchrotron Light Source. The health and national security of the U.S. requires that we maintain a commanding lead in high technology and reduce U.S. vulnerability to critical and strategic imported materials. The ongoing advanced materials research activity is being organized to provide maximum benefit to the Nation. Industry will participate in the design of the research program to assure that it addresses America's high technology needs.

The focus of this effort is on advancing the technical base of information in materials sciences. With the expansion of access and capability at the three sites, the number and diversity of researchers who are able to do collaborative research will be greatly enhanced. Interactions among laboratory, government, industry and university researchers also will be increased at these sites. We expect that the result will be significant advances in materials theory and applications.

The second area with great research potential that I would like to discuss is combustion. The combustion process is one of the most important processes involved in producing the Nation's energy. The potential exists for significant savings in both fuel usage and cost if the efficiency of the combustion process can be improved. Combustion is an extremely complicated series of chemical events that involve a large number of chemical forms, or species, that exist during various stages of the combustion process. Although many of these species are short lived and present only in minute quantities, they are critical to the combustion process.

Long-term basic combustion research requires state-of-the-art techniques to detect these chemical species, obtain basic data on the chemical reactions that occur and create theoretical concepts and computational methods that can be used to understand combustion dynamics. Scientists supported by the BES Chemical Sciences program are carrying out research in all of these areas. The research is being conducted at universities and national laboratories, with the focus at the Department's Combustion Research Facility at Sandia Livermore. The goal is to make combustion chemistry predictable and, thus, of direct use to present and future engineers in the design and development of more efficient combustion systems.

The third research activity I would like to highlight is in our Applied Mathematical Sciences subprogram. Supercomputers are playing an increasingly important role in many of the Department of Energy's (DOE) programs. Every generation of large scientific computers has had a significant positive impact on the ability of the DOE laboratories to meet their mission goals.

Each new machine has improved the laboratories' abilities to model more accurately complex physical phenomena, thus improving their productive capability and reducing the number of expensive tests now required.

This improved capability has been recognized, for example, in the design and testing of nuclear weapons and in magnetic fusion research. In FY 1983, DOE programs in fundamental sciences began to use supercomputers as "experimental" devices for theoretical calculations. Large-scale scientific computers are needed for research in high energy physics, condensed matter research, and chemical and biological theory, among others. Calculations of subatomic particle confinement, critical phenomena in alloy solidification and superconductors, thermophysical properties of chemical mixtures, and properties of long-chain polymers are providing insight into the basic properties of matter.

The Applied Mathematical Sciences subprogram consists of two activities: research and access. The goal of the research portion of the program is to advance our understanding of the fundamental concepts of mathematical modeling involved in the key physical processes being investigated in the Department's mission-oriented programs. Much of the scientific research and development effort throughout DOE is focused directly on analytical and numercial modeling of these physical processes. Basic research in the relationships among the mathematical formulation of scientific and engineering problems and the creation of algorithms for solving these problems on novel computer architectures can be expected to make a significant contribution to the development of future energy production and distribution systems.

The access part of the program is aimed at meeting the immediate needs for supercomputer access by the Department of Energy's High Energy and Nuclear Physics, Biological and Environmental Research, and Basic Energy Sciences programs. This access program will make a substantial contribution not only to solving the national problem of providing access to supercomputers for energy researchers, but also toward furthering research in the programs through the use of state-of-the-art computational tools and techniques. Additionally, this access program helps to ensure that the U.S. maintains its lead in the computational sciences related to supercomputer technology. We have recently brought on-line a class VI computer to provide supercomputer support for these programs and it was over 90% utilized within one month of installation, supporting over 1200 energy researchers at over 60 geographically dispersed locations.

CAPITAL EQUIPMENT

The Capital Equipment request for FY 1986 is $30.5 million. This level of funding is necessary to meet ongoing research requirements, additional commitments associated with the newer facilities and additional equipment for selected areas of promising research. Examples of equipment to be purchased include high resolution nuclear magnetic resonance equipment, computer peripherials (e.g., disk and tape units), a fluid chromatograph for use in analyzing chemical solutions, infrared spectrometers, chemical vapor deposition apparatus, and an x-ray microprobe analyzer.

The requested funding will assure that researchers involved in our program continue to have the modern, sophisticated equipment needed to conduct advanced research.

CONSTRUCTION

Table 4 details the Construction request for FY 1986. Three of the projects, as mentioned earlier, are associated with the enhanced materials initiative which began in FY 1984: the Center for Advanced Materials (CAM) at LBL, the Stanford Synchrotron Radiation Laboratory (SSRL), and the National Synchrotron Light Source (NSLS) at BNL. The CAM project consists of two buildings: A Surface Science and Catalysis Laboratory which will provide state-of-the-art instrumentation and facilities; and the Advanced Materials Laboratory which will be devoted to interdisciplinary study of the synthesis and characterization of energy-related high technology and strategic materials. Both of these facilities will be based on strong programs that exist at the Lawrence Berkeley Laboratory. The FY 1986 budget includes $17.4 million for this project.

At NSLS $7.2 million is requested in FY 1986. This funding continues the project and will meet the demands for a much higher level usage. Additional experimental equipment and space will be provided. When fully instrumented, the NSLS facility will be able to accommodate 90 experiments simultaneously.

Table 4
Basic Energy Sciences
Construction Summary
Budget Authority
($ in millions)

	FY 1986 Request	TEC	Completion Date
Kansas State University Ion Collision Physics Facility	1.9	5.1	FY 1988
Beam Lines and Support Area Construction	7.2	19.7	FY 1987
Center for Advanced Materials	17.4	40.3	FY 1988
Stanford Synchrotron Radiation Laboratory Enhancement	2.6	12.9	FY 1986
Accelerator Improvement and Modification	$ 3.0	$ 3.0	FY 1987
General Plant Projects	4.0	4.0	FY 1987
Total	$36.1		

For the SSRL, the FY 1986 request is $2.6 million to complete the project. This funding will allow us to continue construction of three principal items: the construction of two conventional beam lines, and three special beam line facilities as well as the alteration of the electron storage ring. These improvements will ensure the usefulness of this facility for basic research for many years to come.

The other major project proposed for continued funding in FY 1986 is the Kansas State University Ion Collision Physics Facility; $1.9 million is requested for this project. This facility which is jointly funded by the University, will allow researchers to study the atomic physics of a range of ions unmatched in the world.

The remaining construction funds are requested for General Plant Projects and Accelerator Improvement Projects. For these two construction items the FY 1986 request is $4.0 million and $3.0 million, respectively.

This completes my summary of the BES program. Now I would like to discuss the several Energy Research outlay programs that are related to my statutory responsibilities to advise the Secretary on DOE energy R&D programs, the nonweapons multiprogram laboratories and the education and training of scientists and engineers.

ADVISORY AND ASSESSMENT ACTIVITIES

Within the Office of Energy Research, the Office of Field Operations Management (FOM) and the Office of Program Analysis (OPA) support the Director's statutory and advisory responsibilities. The Office of Field Operations Management provides support with regard to management oversight of the laboratories and energy-related manpower development and training activities of the Department. The Office has developed policies and several management tools that the Department uses to administer its laboratories and R&D facilities across the country. The office also manages the University Research Support, the University Research Instrumentation and the Multiprogram Laboratories Facilities Support programs, each of which I will discuss shortly. The Energy Research Analysis program, managed by the Office of Program Analysis, on the other hand, provides independent and objective program analyses and technical assessments.

ENERGY RESEARCH ANALYSIS

The Energy Research Analysis (ERA) program is the only Departmental program specifically designed to provide independent technical assessments of DOE programs. One of the program's principal tasks is to solicit and obtain credible judgments by premier researchers and expert scientists of the quality of DOE-supported science and its eventual impact. Often following from these judgments are recommendations on the necessary next steps for the research. These recommendations provide independent views on future program directions for DOE program managers to consider. This method of technical review has evolved over the past 5 with participation by several hundred industry, academic and laboratory researchers.

Recent accomplishments include a program assessment of research needs in the Office of Fossil Energy's Advanced Research and Technology Development Program. This program accounts for about 20 percent of the total Fossil Energy FY 1985 budget. Several significant program direction changes resulted from this assessment of over 100 projects by 10 panels of experts.

In the area of technology assessments, a large number have been completed recently including: drilling for both oil and gas; photovoltaics; high level radioactive waste; geothermal energy technology; solar thermal technologies; fuel cell research; and exploration of the continental crust through drilling.

In the area of acid rain, the Office of Program Analysis continues to represent DOE on the Interagency Task Force on Acid Precipitation. This Task Force plans, coordinates, assesses and establishes the budgets for all Federal acid rain research. A recent OPA-sponsored report by the JASON group identified a key scientific uncertainty in atmospheric chemistry: whether a reduction in emissions of SO_2 and NO_x would result in a like or much smaller proportional reduction in acid deposition on sensitive areas. The Energy Research Analysis program has been instrumental in bringing research to bear on this issue; and a National Laboratory Consortium mandated by the Energy Security Act of 1980 (P.L. 96-294) composed of four national laboratories (Brookhaven, Argonne, Pacific Northwest and Oak Ridge) will be heavily involved by FY 1986 in a comprehensive multi-year research effort to resolve this question.

The FY 1986 budget request for the Energy Research Analysis program is $2.7 million. It provides for: (1) one to two independent analyses of DOE R&D programs to evaluate technical merit and future directions; (2) two to three assessments of technologies; (3) support for assessment and coordination elements within the National Acid Precipitation Assessment Program, including support for the Interagency Acid Deposition Assessments Staff and DOE's share of the Program Coordination Office support; (4) support of groups such as the Energy Research Advisory Board (ERAB) and JASON; and (5) technical support on issue papers and alternative action studies, and in international representation of United States Energy R&D future directions to the International Energy Agency (IEA).

UNIVERSITY RESEARCH SUPPORT

The goal of the University Research Support (URS) program is to help maintain strong scientific/technical research capabilities in support of the Department's long-range energy R&D mission in both the university community and the national laboratories. To accomplish this goal, the URS program provides a Departmental focus for several efforts which involve universities, both directly and in conjunction with the Department's national labs. The goals of these interrelated efforts are to:

- Maintain and strengthen university-based energy research and manpower development efforts in selected high priority energy research fields.
- Use the unique resources of the national labs (equipment, instrumentation and personnel) to assist in university faculty and student research and training.
- Increase the number and enhance the quality of students, including women and minorities, pursuing professional level degrees in energy-related science and engineering.
- Help strengthen the scientific/technical workforce in the Department's national labs.

With an FY 1986 budget request of $9.7 million in Operating Expenses, the URS program consists of two major subprograms (Table 5). The first of these is the University/National Laboratory Cooperative Research subprogram, with an FY 1986 Operating Expenses budget request of $8.7 million. This subprogram supports both University Laboratory Cooperative Research and University Reactor Fuel Assistance. One of the objectives of the Cooperative Research activity is to encourage the flow of bright, young research talent for future energy research programs by involving students in ongoing lab research programs. This approach offers the added benefit of making additional research capabilities available to participating university faculty. The second subprogram is Energy Manpower Development

Table 5
University Research Support
Budget Authority
($ in millions)

	FY 1985 Estimate	FY 1986 Request
Operating Expenses		
University/National Laboratory Cooperative Research		
University Laboratory Cooperative Research	$ 6.5	$ 6.8
University Research Fuel Assistance	3.9	1.9
Subtotal	$10.4	$ 8.7
Energy Manpower Development		
Energy Manpower Assessment	0.5	0.5
Energy Education & Training	0.3	0.5
Subtotal	0.8	1.0
Total University Research Support	$11.2	$ 9.7

with a FY 1986 Operating Expenses request of $1.0 million. This subprogram combines two manpower-oriented activities. The Manpower Assessment activity conducts assessments and analyses of the supply and demand of manpower for both current and future energy R&D programs. The Energy Education and Training activity supports projects directed at encouraging secondary school students to pursue energy-related science and engineering programs at the college level.

The FY 1986 budget request for the URS program includes: 1) support for approximately 2200 student and faculty research participation appointments and special training appointments at the Department's labs and major contractors; 2) support for joint research and manpower development efforts with Historically Black Colleges and Universities and for 22 Prefreshman Engineering Program Projects that will reach over 2000 junior and senior high school students; 3) cost-shared support for 30 visiting industrial scientists through the joint DOE National Laboratory-Industry Technology Exchange Research Program; 4) updated manpower assessments for future professional level manpower requirements (e.g., scientists and engineers) for DOE research programs; and 5) refueling of 6-7 university reactors and approximately 20 reactor sharing grants to be made on a competitive basis. This latter activity falls under the University Reactor Fuel Assistance program which provides fuel for university research and training reactors. The university based nuclear research and manpower development effort is highly dependent on these specialized facilities not only for nuclear related training but also for research in the basic sciences.

UNIVERSITY RESEARCH INSTRUMENTATION

Direct access to state-of-the-art scientific research instrumentation equipment is essential for continued progress in advanced, energy-related scientific and technical research. For example, frontier-level materials research in surface science and catalysis requires the ability to describe what is occurring at the atomic and molecular level. This research is essential for understanding such phenomena as carbon gasification, and the composition of surface gases. Instruments used in this research must be able to detect and identify materials at the parts per billion level. Another example is in the field of biological energy research where a major limitation is in understanding the key proteins which influence physiological and genetic factors related to plant productivity. Advances in the analytical capacity of mass spectrometry now offer biological scientists a means to overcome this problem.

Many university scientists do not have direct access to sophisticated, state-of-the-art scientific research instrumentation. This is a serious national problem being addressed through the combined efforts of Federal science agencies, state governments, private industry and by the university community itself. The Federal effort is coordinated by the Office of Science and Technology Policy through the Interagency Committee on University Research Instrumentation. Each participating Federal agency is responsible for supporting university research instrumentation in relation to agency missions and programmatic needs.

The Department's response to this overall national effort is the University Research Instrumentation Program initiated in FY 1984 to help support the purchase on a competitive basis by university researchers of state-of-the-art instrumentation costing in excess of $100,000.

The FY 1986 request for the University Research Instrumentation program is $4.5 million. This level will support an estimated 15 competitively selected awards for instrumentation costing over $100,000. As in prior years, the program will concentrate on those university research groups which have already demonstrated expertise in one of a small number of high priority energy-related topics which are of special concern to the Department's research programs. Among the topics to be considered in FY 1986 are catalysis, bioconversion, engineering research including materials, the geological sciences and environmental research. Each award will be cost-shared with the selected university.

MULTIPROGRAM LABORATORIES FACILITIES SUPPORT

The FY 1986 request for the Multiprogram Laboratories Facilities Support (MLFS) program is $51.2 million (Table 6). The MLFS program consists of two subprograms: Multiprogram General Purpose Facilities (MGPF), initiated in FY 1981, and Environmental Compliance. The goal of the MGPF subprogram, which is managed for the Department by the Office of Energy Research, is to rehabilitate and replace multiprogram general support facilities that are essential to continued operations of the Department's multiprogram laboratory sites. These support facilities include site utilities and support buildings such as laboratories, office buildings and warehouses, roads and railroads, which represent a multibillion dollar government investment.

Table 6
Multiprogram Laboratories Facilities Support
Budget Authority
($ in millions)

	FY 1985 Estimate	FY 1986 Request
Operating Expenses		
Environmental Compliance	$ --a/	$12.9
Capital Equipment		
Environmental Compliance	--	1.0
Construction		
Multiprogram General Purpose Facilities	33.2	29.3
Environmental Compliance	--	8.0
Total MLFS	$33.2	$51.2

a/ Pending approval of a reprogramming request, $5.4 million will be devoted to this activity in FY 1985.

Through continued use and aging, support facilities deteriorate to a point where they are no longer capable of performing their intended functions and must be rehabilitated or replaced. The MGPF program systematically reduces the backlog of deficiencies of these support facilities. It reflects an appropriate Federal responsibility for management of the Government's real property, and we plan to continue the program as a necessary cost of doing business as long as the multiprogram laboratory facilities are used to perform research and development functions for the Department.

The FY 1986 Construction budget request for MGPF is $29.3 million (Table 7) and would continue construction on projects begun in prior years, including chilled water facilities at Brookhaven, Oak Ridge and Argonne National Laboratories, medical facilities at Lawrence Livermore National Laboratory, a fire alarm system at Richland, and an environmental monitoring system at Oak Ridge National Laboratory. The FY 1986 request also includes one new project for fire protection improvements at Brookhaven.

Environmental Compliance is a separate subprogram in FY 1986 because of the magnitude of the requirements at Oak Ridge National Laboratory. As such, it will identify and correct deficiencies at ORNL to ensure compliance with existing state and federal regulations. Over the years, ORNL has generated a variety of radioactive and nonradioactive pollutants which were handled in accordance with existing environmental regulations.

Table 7
Multiprogram General Purpose Facilities (MGPF)
Budget Authority
($ in millions)

Construction	TEC	FY 1986 Request
New Projects		
Fire Protection Improvements, BNL (86-R-726)	$ 3.0	$ 0.5
Prior Year Ongoing Projects		
Central Chilled Water Facility, BNL (85-R-701)	15.0	7.1
Replace Laboratory Roofs, ANL (85-R-702)	9.8	3.1
Electrical Distribution System Restoration, ORNL (85-R-703)	2.2	1.4
Medical Facility Replacement, LLNL (85-R-706)	7.3	2.8
Replace Site Fire Alarm System, RL (85-R-707)	4.8	3.6
Establish a Central Chilled Water Plant, ANL (85-R-709)	5.2	1.0
Upgrade Environmental Monitoring, ORNL (85-R-711)	3.5	2.5
Modify Central Chilled Water Plant, ORNL (85-R-712)	4.7	2.2
Idaho Engineering Research Lab, INEL (80-ES-11)	19.5	0.7
Road Repairs, RL, LBL, INEL, ANL (84-ER-103)	19.5	4.4
Total		$29.3

A number of new regulatory requirements have resulted in the application of more stringent environmental criteria. As a result, long-established procedures and approaches to handling hazardous wastes are no longer acceptable.

The Department is currently working to fully determine the actions necessary to bring ORNL into compliance with all applicable regulations. The Environmental Compliance FY 1986 budget request of $21.9 million will allow initiation of activities to correct environmental deficiencies at ORNL (Table 8). The Operating Expenses request of $12.9 million will allow initial activities in the following areas: process waste system upgrades, hazardous and toxic material management, watershed discharge improvements, spill site characterization and cleanup and upgrades of sanitary and storm sewers. The Capital Equipment request of $1.0 million is for equipment necessary to provide for the cleanup activities. The Construction request of $8.0 million is for general plant projects and design work for the Non-radiological Process Waste Treatment Project. The Department has proposed a $5.4 million reprogramming in FY 1985 to initiate this activity.

ADVISORY AND OVERSIGHT PROGRAM DIRECTION AND POLICY AND MANAGEMENT

The FY 1986 budget request for Advisory and Oversight Program Direction is $2.9 million. These funds are required to provide for the salaries, benefits, travel and other expenses associated with 44 full-time equivalents. The FY 1986 request will provide the staffing resources

Table 8
Environmental Compliance
Budget Authority
($ in millions)

	FY 1985 Estimate	FY 1986 Request
Operating Expenses	$ 0[a]	$12.9
Capital Equipment	0	1.0
Construction	0	8.0
Total	$ 0[a]	$21.9

[a] Pending approval of a reprogramming request, $5.4 million will be devoted to this activity in FY 1985.

required by the Director of Energy Research to carry out his responsibilities under legislation (P.L. 95-91) and those mandated by the Secretary in areas beyond the scope of other ongoing Energy Research programs.

The FY 1986 budget request for Policy and Management is $.5 million. These funds are required to provide for the salaries and related expenses associated with 8 full-time equivalents in the Office of the Director of Energy Research.

Mr. Chairman, that concludes my testimony. I would be happy to answer your questions.

STATEMENT OF ALVIN W. TRIVELPIECE, DIRECTOR OF ENERGY RESEARCH, DEPARTMENT OF ENERGY

Mr. Chairman and Members of the Subcommittee:

It is a pleasure to be here today to present the FY 1986 budget request for the High Energy and Nuclear Physics (HENP) programs. The budget request is shown in Table 1 which gives the total FY 1986 request for programs supported by the Office of Energy Research.

The High Energy and Nuclear Physics programs continue to be an essential investment in the Nation's science and technology enterprise. Achievement of the Nation's economic goals will depend in large part on knowledge produced by a strong, broad national science capability. There are strong indications that investment in human capital is no less important to the economy than machine tools and industrial plants and that the advance of scientific knowledge is a significant factor in the growth in productivity of the United States.

The support of long-range basic research is the responsibility of government; and an appropriate Federal role is for mission agencies such as the Department of Energy (DOE) to support the foundation of basic science as well as mission-oriented applied research in appropriate disciplines. The FY 1986 budget request for the HENP programs recognizes that, even in a year of challenging and necessary budget constraints, well-chosen basic research will continue to contribute to the nation's economic growth, well-being and national defense.

The High Energy and Nuclear Physics programs seek the answers to questions that man has asked for many hundreds of years, namely, what are the basic constituents of matter and what forces govern them. Twenty-five-

Table 1
Office of Energy Research
Summary by Program
($ in millions)
Budget Authority

	FY 1985 Estimate	FY 1986 Request
General Science & Research		
High Energy Physics	$545.6	$510.1
Nuclear Physics	182.8	172.9
General Science Program Direction	2.2	2.4
Subtotal	$730.6	685.4
Energy Supply - R&D		
Basic Energy Sciences	$422.6	409.8
Magnetic Fusion Energy	437.0	390.0
Biological & Environmental Research	190.5	186.3
Energy Research Analysis	3.0	2.7
University Research Support	11.2	9.7
University Research Instrumentation	5.0	4.5
Multiprogram Laboratories Facilities Support	33.2	51.2
Advisory & Oversight Program Direction	2.8	2.9
Policy and Management	0.5	0.5
Subtotal	$1,105.8	$1,057.6
Total ER	$1,836.4	$1,743.0

hundred years ago, Aristotle believed that the basic constituents of matter were earth, fire, air and water. It was not until the early 17th century that true experimental study began; and only at the beginning of the 20th century did the field of particle physics take shape as scientists began to understand that the atom was not a fundamental particle but was composed of a nucleus and electrons.

In the 1930's, the field of nuclear physics grew as physicists learned that the nucleus is composed of even smaller constituents (protons and neutrons). As scientists gained a deeper understanding of the nucleus in the mid-1950's, they began to realize that an even more fundamental level of matter must exist. In the last 25 years, remarkable progress has been made in high energy physics, the field that focuses on discovering and understanding the fundamental constituents of matter and the forces of nature that govern them.

The High Energy and Nuclear Physics programs have made significant contributions not only to energy resource development, but to education, health, industry and national defense. Contributions to the economic growth and prosperity of the Nation have come directly from the results of the research, from technological spinoffs and from the training of tomorrow's scientists through participation of university graduate students in carrying out the research. Through technology transfer, these ideas and people have made contributions in a variety of industries including medical instrumentation, control and instrumentation of industrial processes, the production of nuclear energy, and many applications of electronic and computer techniques.

The High Energy and Nuclear Physics programs are closely related not only in terms of overall goals, but also in the types of facilities and equipment used to reach these goals and the impact that research in one program has on the other. Both seek to contribute to an understanding of the basic constituents of matter and the forces that govern them. Nuclear Physics does so by studying the nucleus; High Energy Physics does so by studying the most fundamental of particles that comprise the nucleus and all other matter.

Experiments in both the High Energy and Nuclear Physics programs depend on large experimental facilities that accelerate beams of particles to collide with stationary targets or head-on with other moving particle beams. Studying the results of these collisions helps scientists to learn about the properties of the underlying building blocks and basic forces involved. Although research progress depends on the availability of these forefront accelerator and colliding beam facilities, as well as on the dete record the results of the collisions, progress also depends on a continuing interplay of advancements in experiment, theory and technology. Often the range of experiments possible is determined by available technology; and physicists frequently have to invent new equipment and technology to carry out the most important experiments.

In the High Energy Physics program, research utilizing accelerators is conducted principally at four major accelerator laboratories in the U.S., two in Europe and one in Japan and encompasses more than 150 user groups. The Nuclear Physics program, carried out at seven national facilities, accommodates approximately 70 user groups. The program also utilizes facilities in Canada and Europe. Participants from over 100 universities across the country and from more than 50 foreign institutions contribute to the success of the High Energy and Nuclear Physics programs.

HIGH ENERGY PHYSICS

Progress toward improving our understanding of energy and matter and their most elemental transformations has come rapidly in recent years. In developing this knowledge, five U.S.-supported high energy physicists have won or shared in Nobel prizes during the last 6 years. The major current objective of high energy physics research is unification of the basic forces into a single theoretical framework; in other words, a single theory that would desribe all of the interactions of matter and energy existing in the universe.

The ultimate goal is to link together, or unify, the four known forces of nature. The electromagnetic force describes how atoms and molecules are formed and is the cornerstone to understanding chemistry, electronic communications and biological processes. The weak nuclear force describes processes such as the radioactive decay of nuclei. The strong nuclear force helps describe how the sun and the stars produce so much energy. Together with the weak nuclear force, it also describes the relative abundance of the chemical elements. The gravitational force, perhaps the most familiar of the forces of nature, explains such things as how objects fall and planets move in their orbits.

Results of high energy physics research have led to an increasingly better understanding of the forces of nature and the unifying connections among them. A part of the recent progress in high energy physics has been the conceptual unification of the weak nuclear and electromagnetic forces into a single "electroweak" framework. There is increasing anticipation that the unification of the strong nuclear and electroweak forces into one "grand unified" framework may be possible, thus reducing the apparent number of forces in nature to two. The ultimate goal is to determine whether the gravitational force can be incorporated into a "super-grand" unification that would bring all of the forces in nature into a single unified framework.

FY 1986 HIGH ENERGY PHYSICS BUDGET REQUEST

The FY 1986 request for the High Energy Physics program is $510.1 million, which consists of $391.5 million for Operating Expenses, $63.1 million for Capital Equipment and $55.5 million for Construction (Table 2).

A major part of the funding for the program is required to meet the direct needs of the accelerator laboratories to develop, maintain and operate the major accelerator, colliding beam and detector facilities. In FY 1986, the accelerator and colliding beam facilities include: the 30 GeV (billion electron volts) proton synchrotron, called the Alternating Gradient Synchrotron, at Brookhaven National Laboratory (BNL); the 1000 GeV superconducting magnet proton synchrotron at Fermi National Accelerator

Table 2
High Energy Physics
Budget Authority
($ in millions)

	FY 1985 Estimate	FY 1986 Request
Operating Expenses		
Physics Research	$107.5	$111.3
Facility Operations	175.2	187.8
High Energy Technology	90.2	92.4
Subtotal	$372.9	$391.5
Capital Equipment	58.7	63.1
Construction	114.0	55.5
Total High Energy Physics	$545.6	$510.1

Laboratory (Fermilab); and the 32 GeV linear electron accelerator at the Stanford Linear Accelerator Center (SLAC). SLAC also has two electron-positron colliding beam facilities for which the linear accelerator acts as the injector: the Stanford Positron Electron Asymmetric Ring (4 GeV x 4 GeV) and the Positron-Electron Project (15 GeV x 15 GeV). The facilities at these laboratories provide the source of experimental data for most of the High Energy Physics research, more than 75% of which is carried out by university-based scientists. The overall utilization level of [illegible] accelerator facilities in FY 1986 will be in the 45-50 percent range.

The FY 1986 Operating Expenses request is $391.5 million. A major feature of the program will be the operation of the Tevatron superconducting synchrotron at Fermilab in the 800-1000 GeV energy range. Operation at this level for fixed-target experiments was made possible by upgrading experimental areas and beam lines external to the main ring. Also in FY 1986, pre-operating tests of the proton-antiproton colliding beam capability provided by Tevatron I will be carried out.

The program also will include operation of and research at the Alternating Gradient Synchrotron at BNL with its new unique high energy polarized proton beam and, at SLAC, operation of the Positron Electron Project and pre-operating systems tests of the Stanford Linear Collider. The FY 1986 budget request also includes funding to continue advanced technology R&D.

Part of this effort is the continuation of research and development on the large accelerator collider called the Superconducting Super Collider (SSC), for which the FY 1986 budget request includes $20 million. It is envisioned as a proton-proton collider with an energy of 20 trillion electron volts per beam. If built, the SSC would provide a research capability in an unexplored domain for which there are no existing or planned facilities anywhere in the world and in which there is strong expectation of major research breakthroughs. In FY 1986, SSC-related R&D continues with emphasis on advanced accelerator R&D to develop a cost/performance optimized design for the selected superconducting magnet type, as well as cost effective techniques for fabricating the superconducting magnets.

The FY 1986 Capital Equipment request of $63.1 million provides a small increase above the FY 1985 level to help meet the highest prior[illegible] associated with the initial complement of detectors and secondary beams being provided by the Tevatron projects at Fermilab and by the Stanford Linear Collider at SLAC. These initial detectors and beams account for $30.6 million of the total Capital Equipment request. The total Equipment request for FY 1986 is essential for effective use of existing facilities and the new facilities being completed in FY 1985 and 1986 at Fermilab and SLAC.

The FY 1986 Construction request is $55.5 million. The projects are listed in Table 3. A major portion of this request is for completing the construction of the Stanford Linear Collider at SLAC. The primary goal of this project is to develop and demonstrate the technical feasibility of

Table 3
High Energy Physics
Budget Authority
($ in millions)

Construction	FY 1986 Request	TEC	Completion Date
Tevatron I (81-E-218)	$ 8.6	$ 84.0	FY 1986
Stanford Linear Collider (84-ER-133)	22.9	115.4	FY 1986
Central Computing Upgrade, Fermi (86-R-104)	3.1	23.9	FY 1988
Accelerator Improvement Project (86-R-102)	10.5	10.5	FY 1988
General Plant Projects (86-R-103)	10.4	10.4	FY 1988
Total Construction	$ 55.5		

using linear accelerators with precisely controlled, high intensity and highly focused beam pulses to provide high rates of electron-positron collisions at energies far beyond those that will be affordable for circular colliders. It also will provide early access to the important physics regime in which Z^0 particles are copiously produced. The Z^0 particles are one of a family of particles that carry the electroweak force. In addition, the request provides for completion of the Tevatron I project at Fermilab. Tevatron I will be the highest energy collider in the world. The Construction request also provides for upgrading of the central computing capability at Fermilab. This upgrade computing capability at Fermilab is essential for effective analysis of the large volume of new physics data coming from the Tevatron program.

Funds are requested for Accelerator Improvement Projects ($10.5 million) that are critical on an annual basis to maintain the scientific effectiveness and the operating reliability and efficiency of the accelerator and colliding beam facilities. The request also provides $10.4 million for General Plant Projects (GPP) which are required to keep the general plant of the laboratories (e.g., buildings, roads, utilities) in operating condition.

NUCLEAR PHYSICS

The Nuclear Physics program is a comprehensive program of interdependent experimental and theoretical investigations of atomic nuclei. The goal of the program is to understand the interactions, properties and structures of atomic nuclei and nuclear matter at an elementary level and, as a complement to high energy physics research, to learn about the fundamental forces of nature by using nuclei as a proving ground.

The behavior of nuclei and nuclear matter determine the physical properties of our universe--from its creation as a primordial mix of energy and elementary particles, to the reactions that power our sun and the particles and forces that make up our planet. An understanding of nuclei and nuclear phenomena is essential to any basic understanding of the world around us.

In terms of trained researchers, new knowledge and advanced instrumentation, the Nuclear Physics program is a central component in the Nation's long-term investment in its technological future. Nuclear knowledge, techniques, instruments and applications have become an integral part of American society. They serve as the basis for our national defense, for therapeutic and diagnostic medical applications, for generation of electricity with nuclear reactors and for a large and diverse array of applications in the commercial sector.

Based on recent research results, nuclear physicists are optimistic that a new level of understanding of atomic nuclei is achievable. This optimism stems from evidence that the mesons, protons and neutrons that are inside nuclei are themselves composed of yet smaller particles called quarks and gluons. It is also based on the likelihood that the theory called quantum chromodynamics can be developed into a theory that correctly describes the interaction between quarks and gluons and is also an exact theory of the strong nuclear force.

The FY 1986 Nuclear Physics program will emphasize continued experimental investigation of the behavior of quarks inside nuclei and of the way in which quarks determine the makeup and properties of nuclei. In nuclear theory, emphasis in FY 1986 will be on understanding the limitations of the present quantum chromodynamics theories as exact theories of the nuclear force, on improving these theories, and on understanding the ways in which new quark configurations would become evident.

FY 1986 NUCLEAR PHYSICS BUDGET REQUEST

The FY 1986 budget request for the Nuclear Physics program is $172.9 million. Of that amount, $151.9 million is for Operating Expenses; $14.0 million is for Capital Equipment; and $7.0 million is for Construction (Table 4). Almost half of the Operating Expenses request ($81.3 million) is needed for operation of accelerator facilities. In FY 1986, the national facilities are expected to achieve an overall utilization rate of 45%.

Table 4
Nuclear Physics
Budget Authority
($ in millions)

	FY 1985 Estimate	FY 1986 Request
Operating Expenses		
Medium Energy Nuclear Physics	$ 74.6[a]	$ 76.5
Heavy Ion Nuclear Physics	49.4	52.6
Low Energy Nuclear Physics	13.5	13.4
Nuclear Theory	9.3	9.4
Subtotal	146.8	$151.9
Capital Equipment	12.7	14.0
Construction	23.3	7.0
Total Nuclear Physics	$182.8	$172.9

[a] Includes $3.1 million which was provided by Defense Programs for LAMPF facility operations.

As is the case with High Energy Physics, the Nuclear Physics program depends upon the operation of large and complicated accelerator facilities to provide a variety of projectile beams required for forefront nuclear research. The existing accelerator facilities are supported by the Nuclear Physics program as national facilities whose beam time is made available to all the Nation's scientists on the basis of the scientific merit and technical feasibility of proposed research projects. The national facilities are: the Clinton P. Anderson Meson Physics Facility (L[illegible] at Los Alamos National Laboratory (LANL); the Bates Linear Accelerator Center at the Massachusetts Institute of Technology (MIT); the SuperHILAC/Bevalac at Lawrence Berkeley Laboratory (LBL); the Argonne Tandem/Linac Accelerator System (ATLAS); the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory (ORNL); the 88-inch Cyclotron at LBL; and the Double MP Tandem Van de Graaff facility at Brookhaven National Laboratory (BNL). To complement these national facilities, the Nuclear Physics program also supports on-campus accelerators at several universities: Yale, Duke, the University of Washington and Texas A&M.

The FY 1986 Nuclear Physics budget request includes funds for initial heavy ion nuclear research and accelerator operations at the Alternating Gradient Synchrotron (AGS) at BNL. Upon completion in FY 1986, the Tandem/AGS Heavy Ion Transfer Line will provide heavy ion beams to the AGS for acceleration to energies and masses not possible anywhere else in the world. This unique capability offers the possibility that scientists may be able to create exotic new states of nuclear matter never before observed in the laboratory.

Another major feature of the FY 1986 Nuclear Physics program is the continuation of R&D and architect and engineering activities to better define the Continuous Electron Beam Accelerator Facility Project's (CEBAF) scope, schedule and total cost. In FY 1986, $5.0 million in Operating Expenses are requested for this purpose. This work is aimed at establishing a technical base so that construction could be initiated in FY 1987.

CEBAF is projected to be a major facility centering on an electron linear accelerator/stretcher ring complex capable of delivering intense, continuous beams in the energy range from 0.5 to 4 billion electron volts. Ultimately, CEBAF would have the capability of addressing a crucial class of investigations facing nuclear physics today, namely, understanding the relationship between the traditional and emerging descriptions of nuclear dynamics. More specifically, CEBAF would provide unique research opportunities to U.S. scientists and, through international collaboration, to scientists from abroad. CEBAF would make it possible for these scientists to investigate the ways in which quarks that are bound in neutrons and protons influence the makeup and behavior of nuclei. They would also be able to study how quarks interact while embedded within nuclear matter and to test quantum chromodynamics as the fundamental theory of the strong nuclear force.

The Capital Equipment request of $14.0 million would provide for particle detection systems, data acquisition and analysis systems, and instrumentation to improve the performance of Nuclear Physics accelerators. These funds are essential for the effective operation of the national accelerator facilities operated by the Nuclear Physics program. Of the total request, $13.2 million are required for projects at BNL, LBL, ORNL, Argonne National Laboratory, the Clinton P. Anderson Meson Physics Facility at LANL, Bates Linear Accelerator Center at MIT, Oak Ridge Associated Universities and Duke University. Since the Nuclear Physics program is responsible for providing all of the general purpose equipment at LBL, the remaining $.8 million is for that purpose.

The FY 1986 Construction request of $7.0 million (Table 5) is for Accelerator Improvements and Modifications projects ($3.5 million) and for General Plant projects ($3.5 million). These projects are needed to maintain the scientific effectiveness, reliability and efficiency of Nuclear Physics facilities.

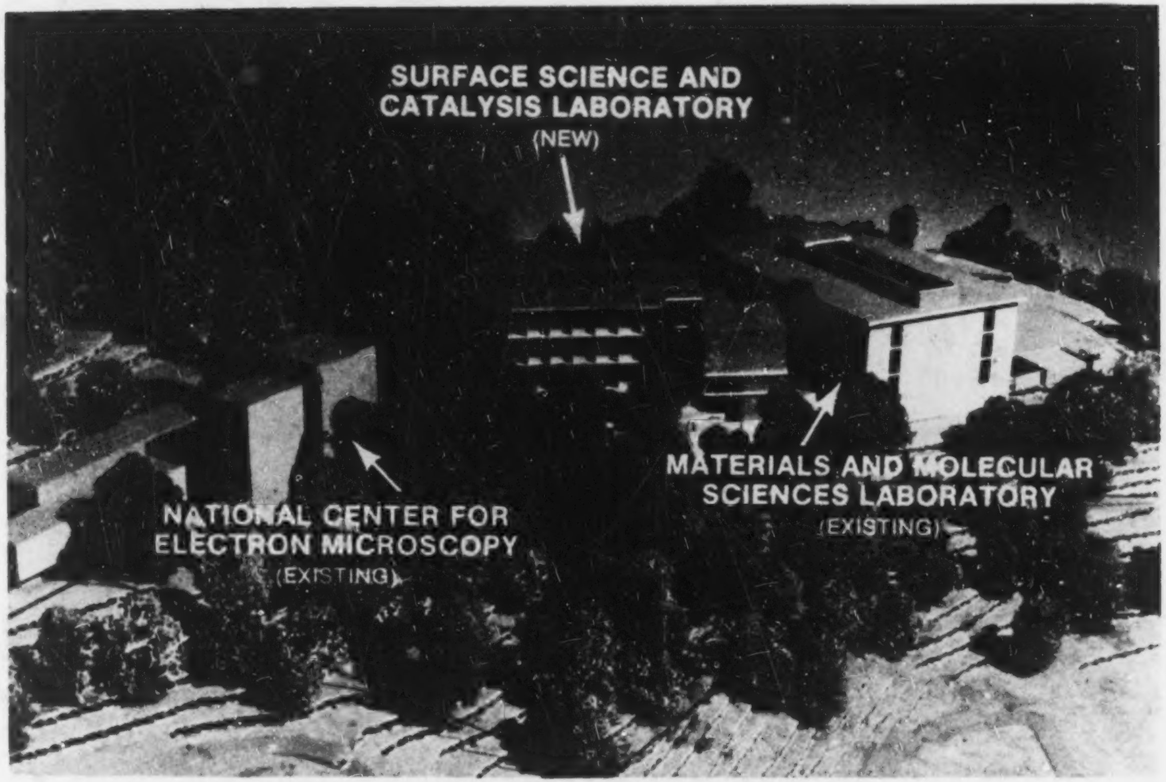
GENERAL SCIENCE PROGRAM DIRECTION

The FY 1986 budget request for General Science Program Direction is $2.4 million. These funds are required to provide for the salaries, benefits, travel and other expenses associated with 39 full-time equivalents in the Office of the Associate Director for High Energy and Nuclear Physics and associated support staff required to administer these programs.

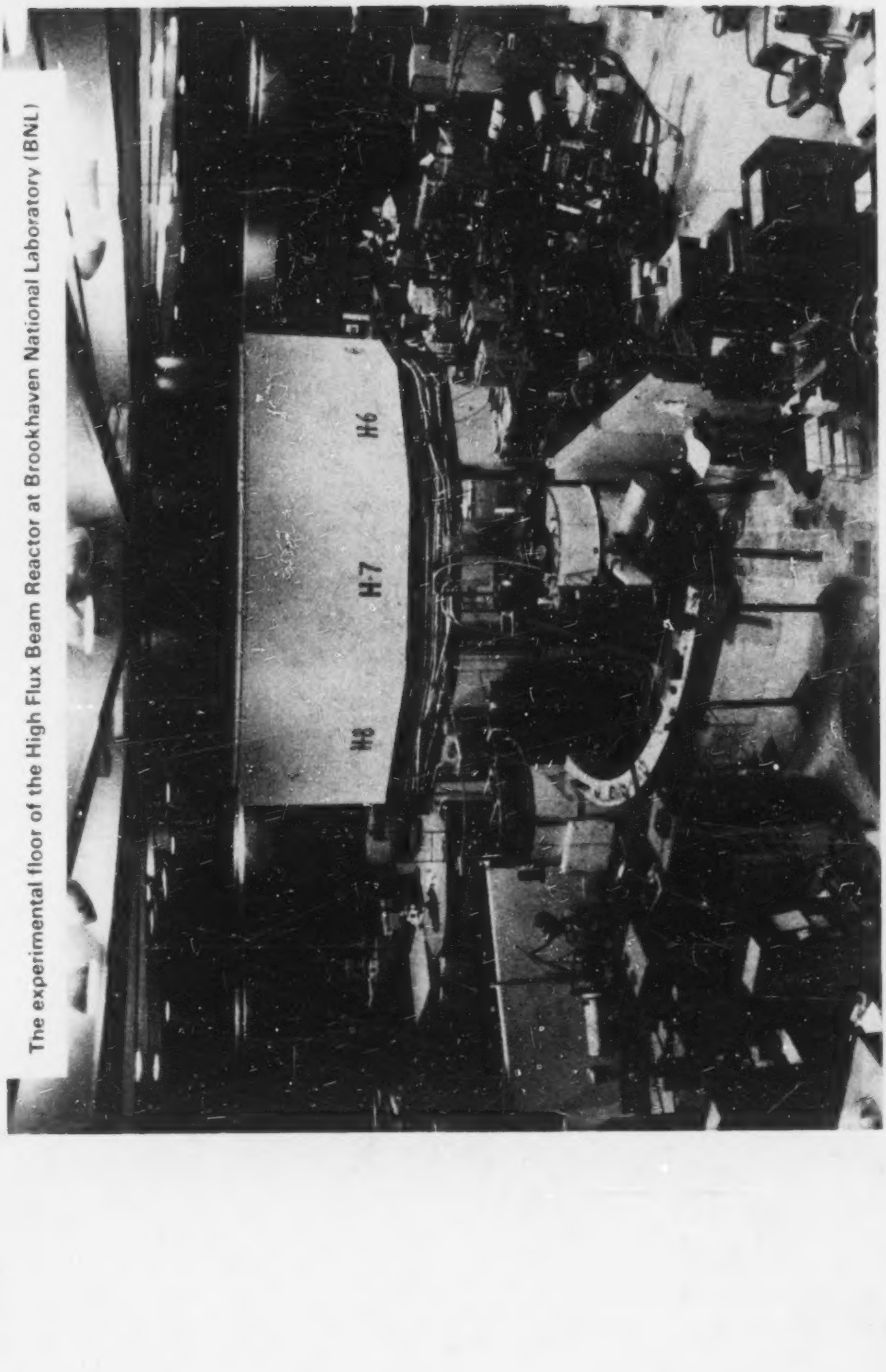
Mr. Chairman, that concludes my testimony. I would be happy to answer questions.

Table 5
Nuclear Physics
Budget Authority
($ in millions)

Construction	FY 1986 Request	TEC	Completion Date
Accelerator Improvements Projects (86-R-204)	3.5	3.5	FY 1988
General Plant Projects (86-R-205)	3.5	3.5	FY 1988
Total Construction	7.0		

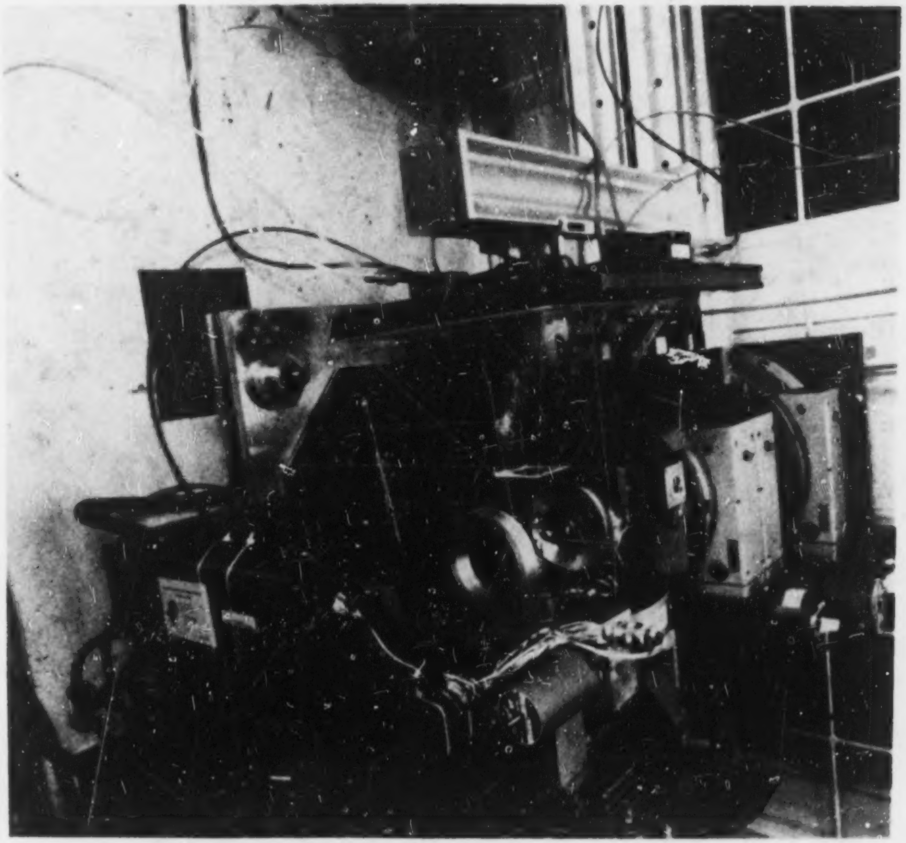

SURFACE SCIENCE AND CATALYSIS LABORATORY
(NEW)
NATIONAL CENTER FOR ELECTRON MICROSCOPY
(EXISTING)
MATERIALS AND MOLECULAR SCIENCES LABORATORY
(EXISTING)

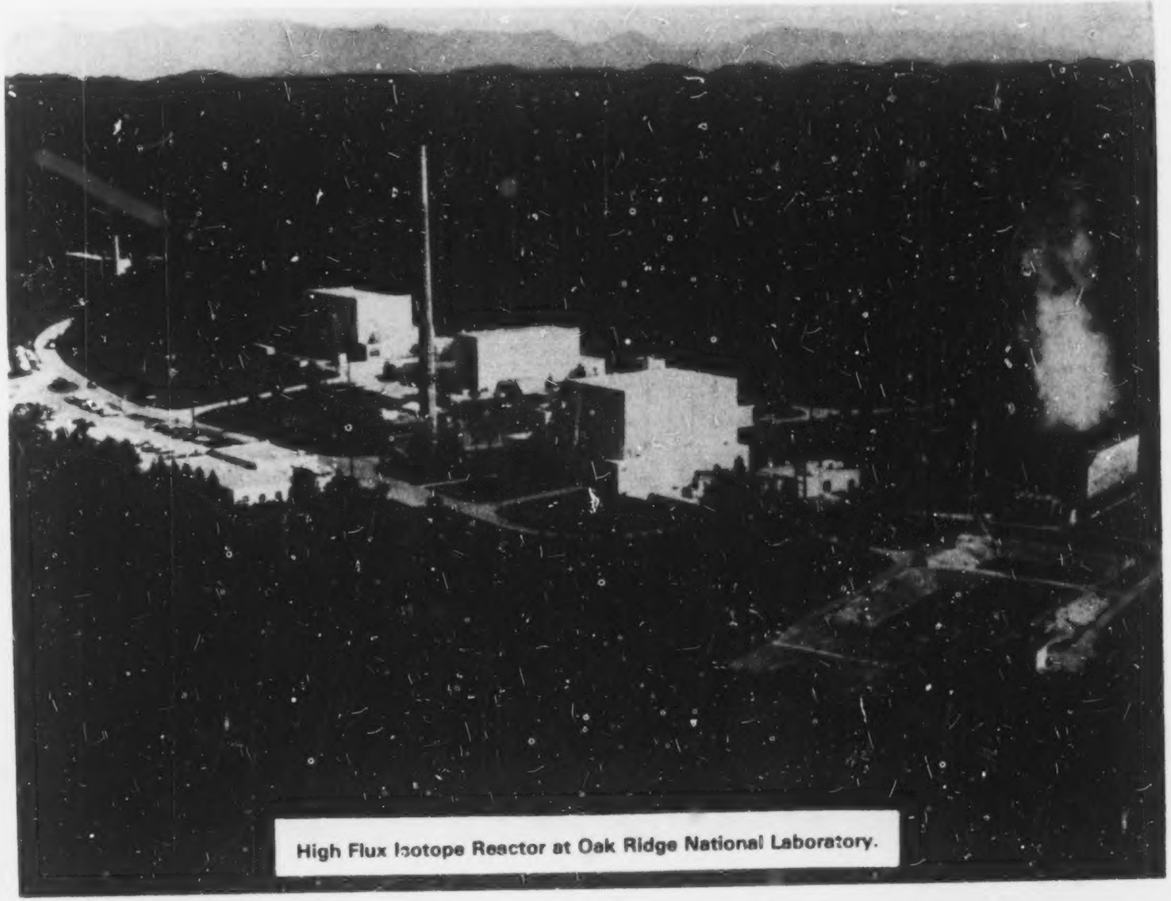
Model showing Surface Science and Catalysis Laboratory (SSCL), National Center for Electron Microscopy (NCEM) and Materials and Molecular Sciences Laboratory. SSCL is part of the new Center for Advanced Materials at Lawrence Berkeley Laboratory aimed at enhancing interaction between basic materials research and industry.



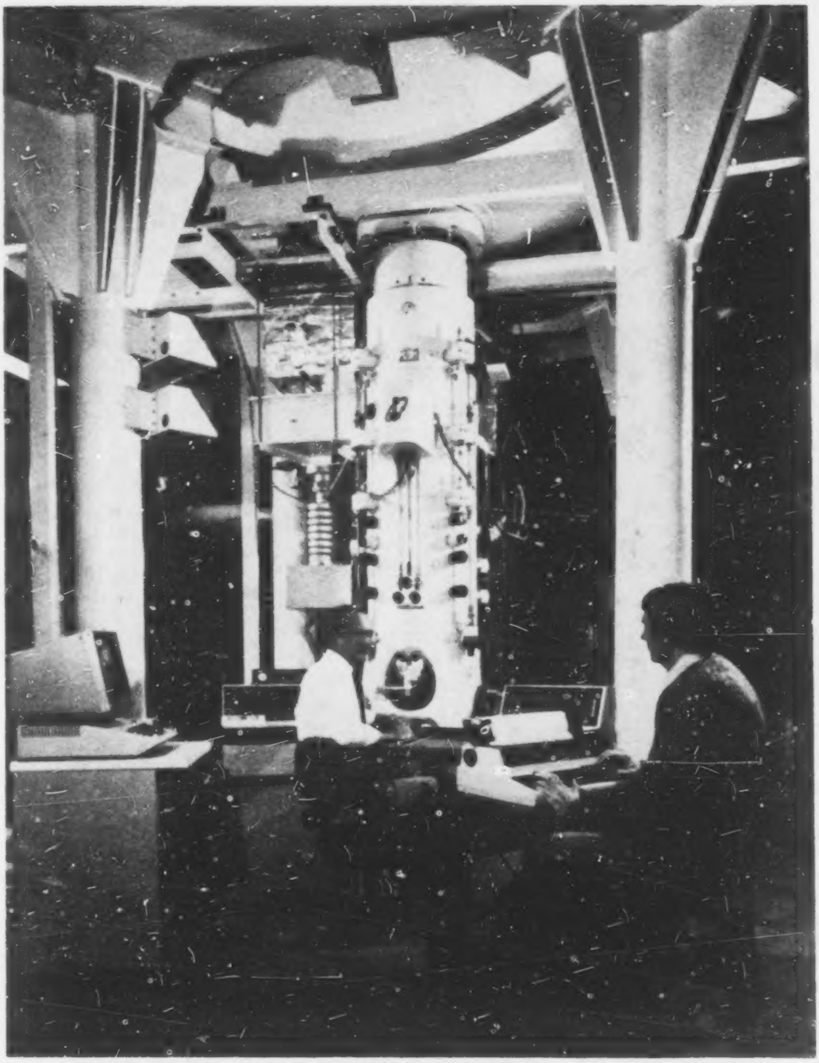
The experimental floor of the High Flux Beam Reactor at Brookhaven National Laboratory (BNL)

An experimental station at the Stanford Synchrotron Radiation Laboratory used to determine the 3-dimensional structure of proteins and other large biological structures by x-ray crystallography

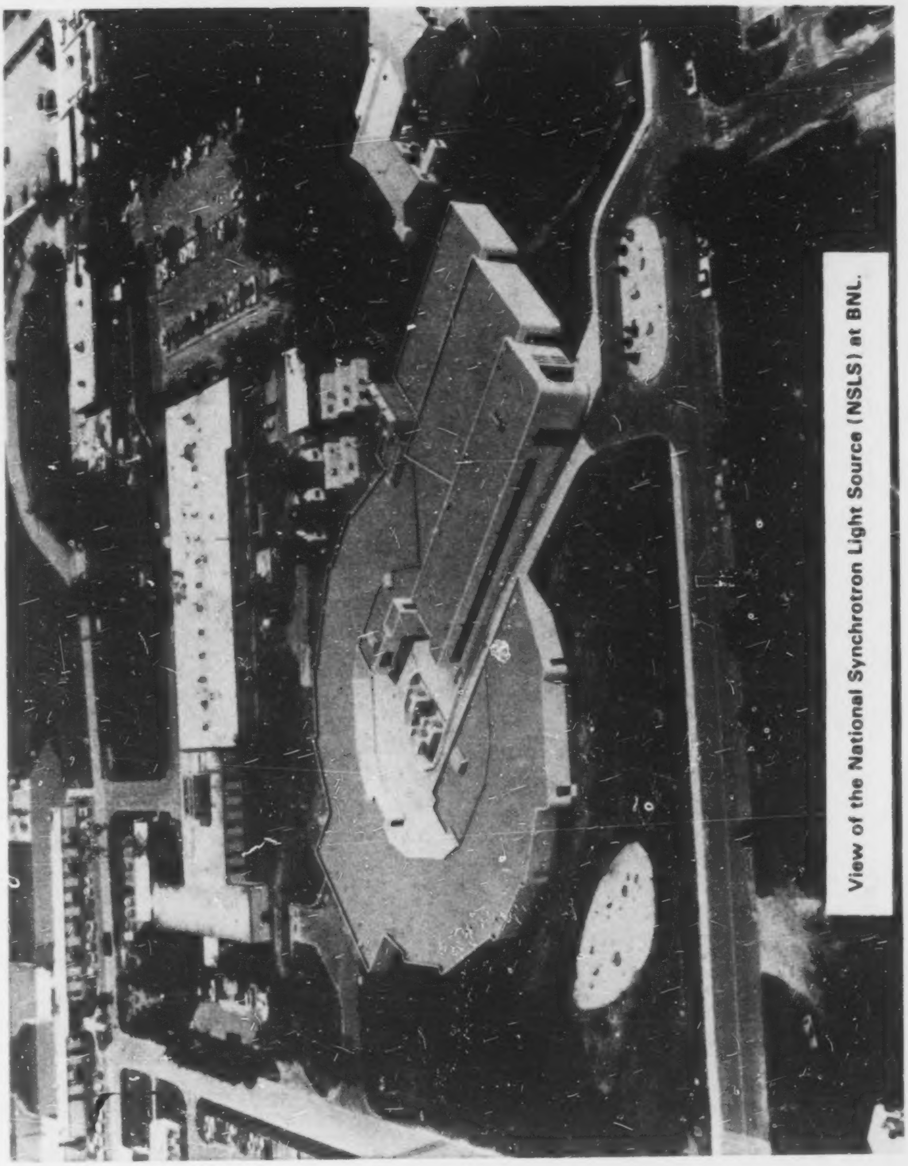




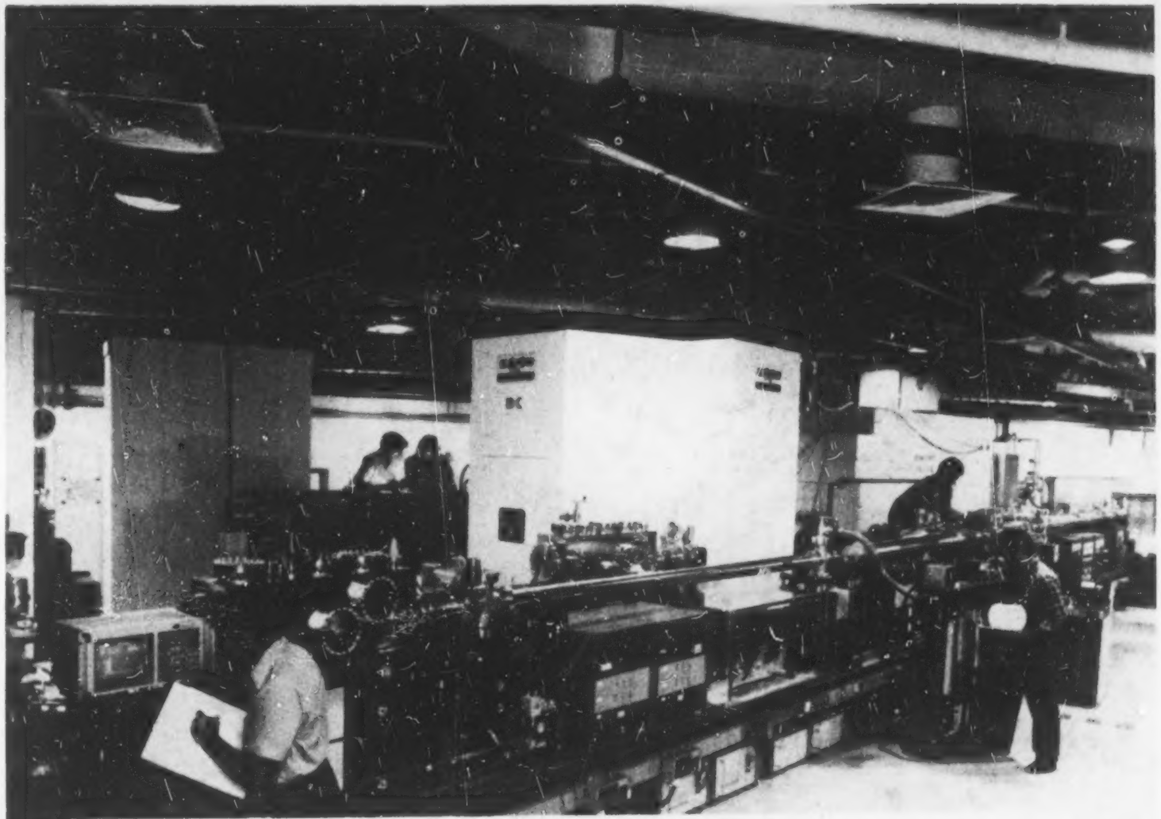
High Flux Isotope Reactor at Oak Ridge National Laboratory.



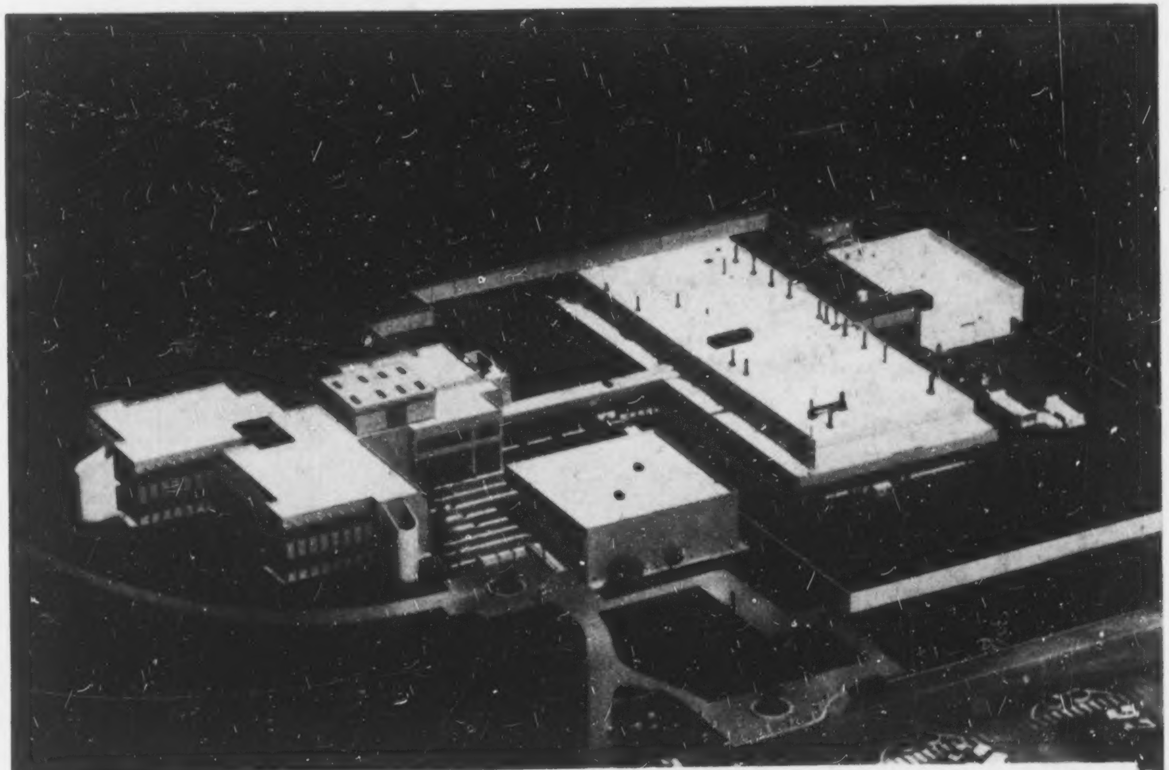
The Atomic Resolution Microscope - one of several advanced microscopes at NCEM it is a unique instrument that achieved, for the first time, direct images of the atomic structure of solids



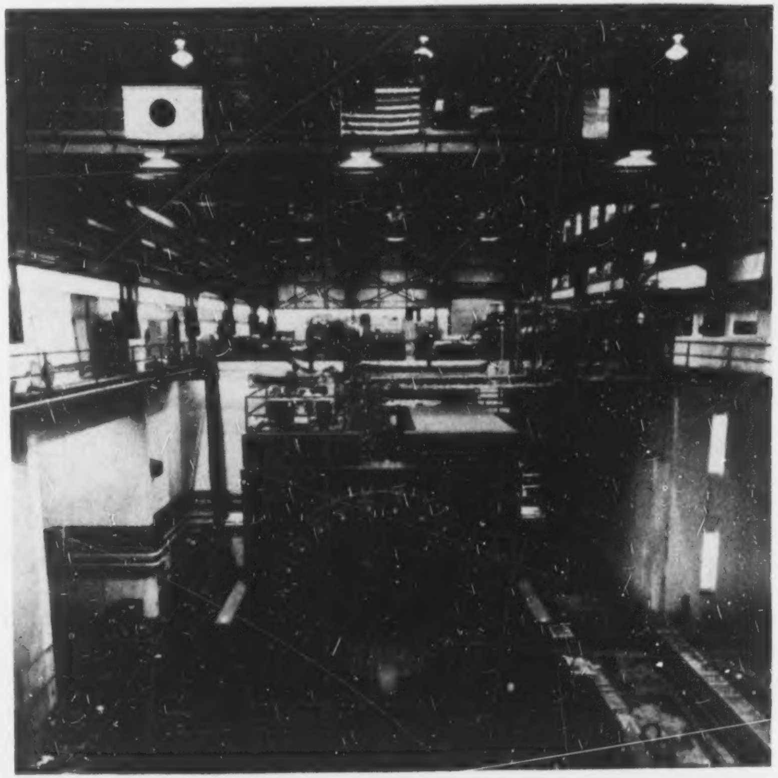
View of the National Synchrotron Light Source (NSLS) at BNL.



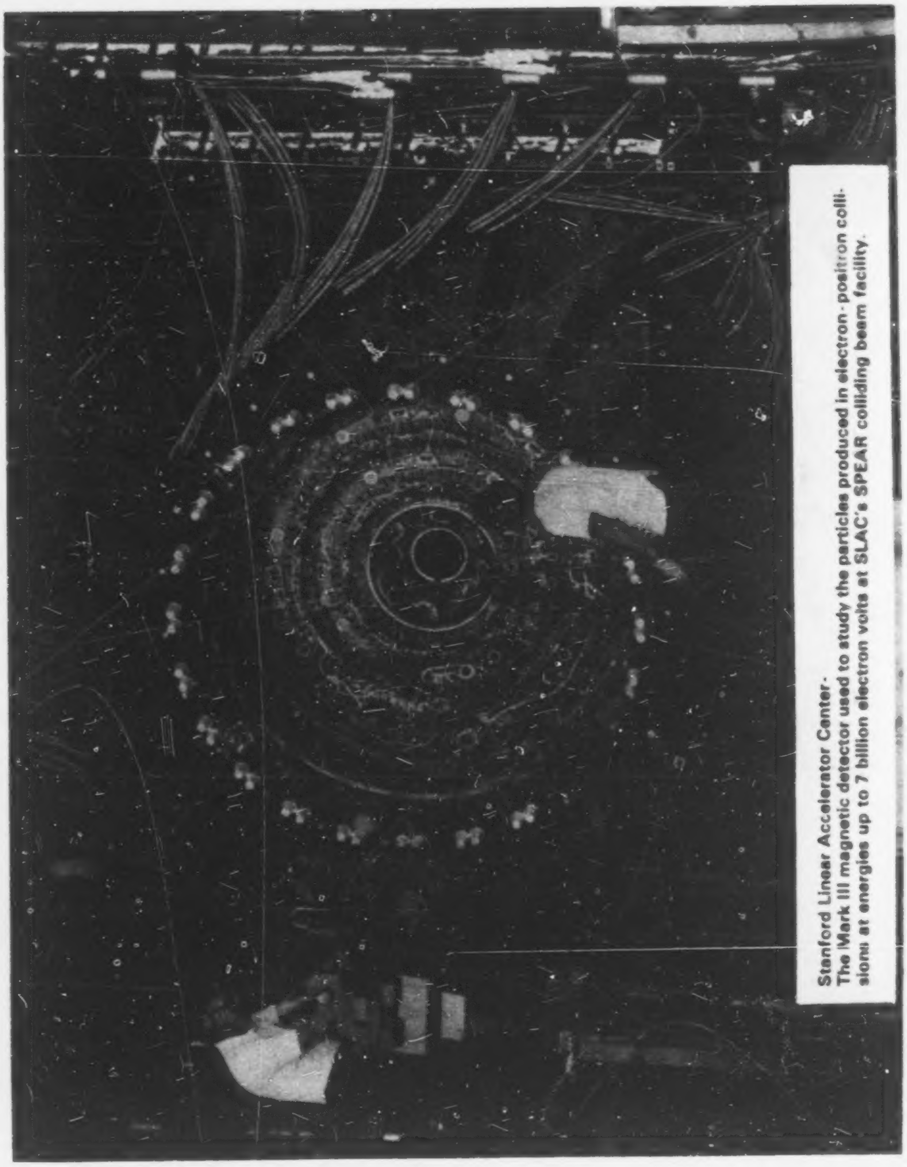
At NSLS, one of the experimental set ups with equipment provided by industry (Exxon in this case) to carry out basic research.



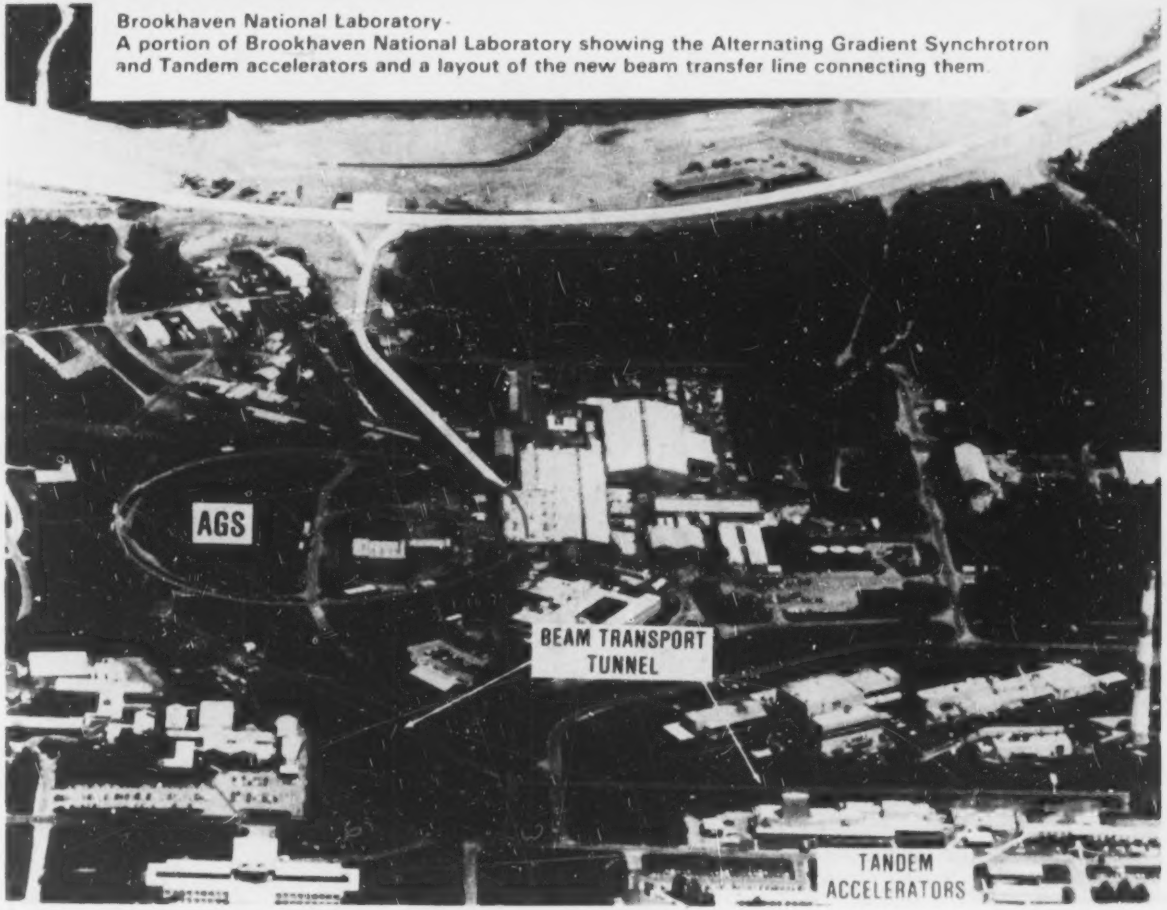
An overhead view of the Combustion Research Facility at Sandia - Livermore. It houses unique laser research facilities and provides experimental capabilities for visiting scientists including industry.



Fermi National Accelerator Laboratory.
Collider detector now being assembled at Fermilab by a U.S.-Japanese-Italian collaboration for studies of antiproton-proton interactions at Tevatron's planned 2 trillion electron volt (TeV) reaction energy.



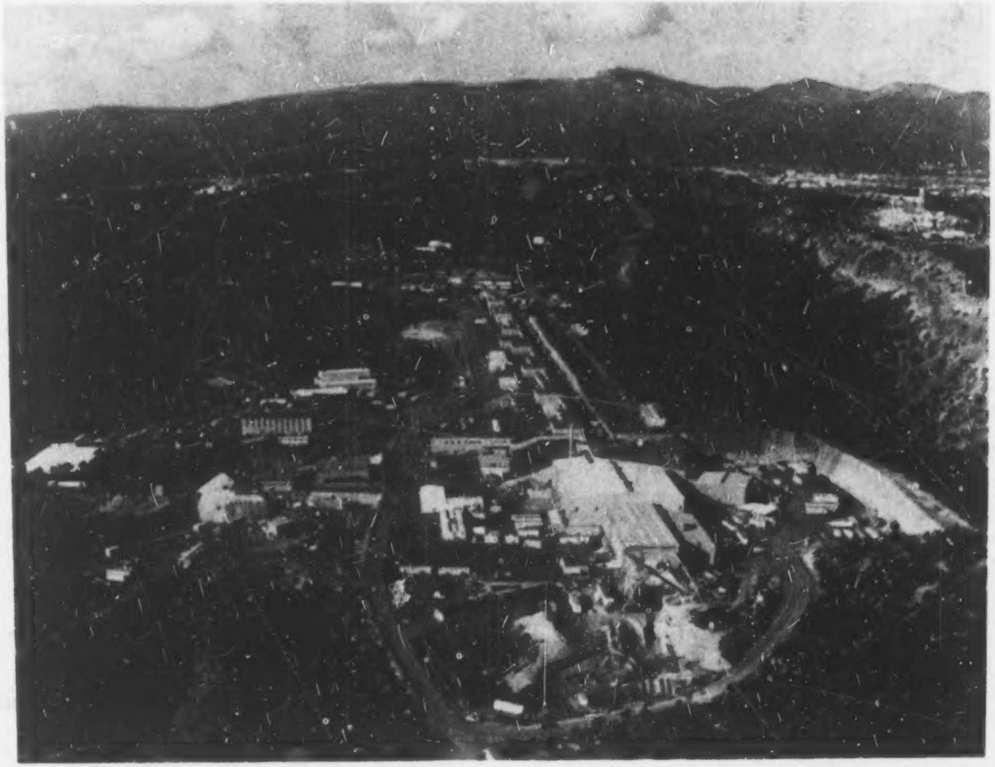
Stanford Linear Accelerator Center.
The Mark III magnetic detector used to study the particles produced in electron-positron collisions at energies up to 7 billion electron volts at SLAC's SPEAR colliding beam facility.

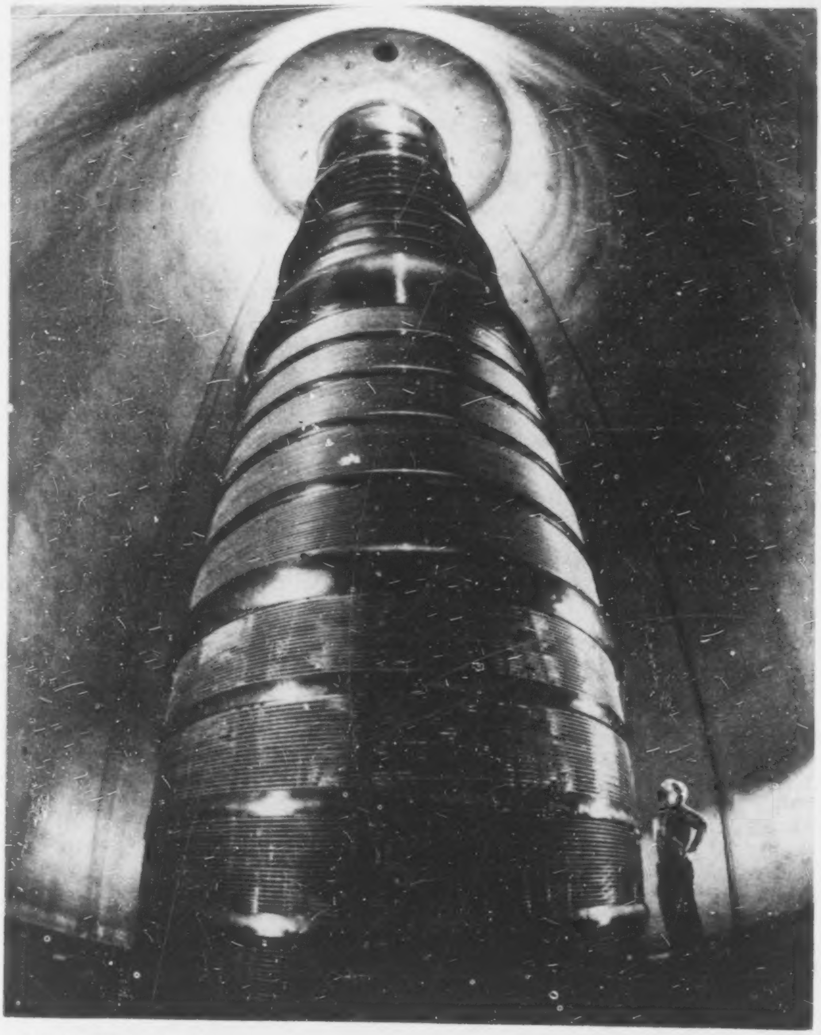

AGS
BEAM TRANSPORT TUNNEL
TANDEM ACCELERATORS

Brookhaven National Laboratory-
A portion of Brookhaven National Laboratory showing the Alternating Gradient Synchrotron and Tandem accelerators and a layout of the new beam transfer line connecting them.

Los Alamos National Laboratory

The Clinton P. Anderson Meson Physics Facility at Los Alamos. The linear accelerator (2585 feet in length) provides 800 MeV protons beams for fundamental nuclear, particle, atomic, weapons, and material research.





Oak Ridge National Laboratory -
High voltage column of 25 million volt electrostatic accelerator at Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory.

DISCUSSION

Mr. **Fuqua**. Thank you, Dr. Trivelpiece.

One of the questions that I am concerned about is with the proposed budget request for Basic Energy Sciences. Will that be relatively the same number, or fewer investigators supported in that budget?

Dr. **Trivelpiece**. The reduction is mostly in construction, and the operating budget is approximately the same. And to the level at which we're discussing the ability to answer that today, it is the same number.

Mr. **Fuqua**. In the construction area, I understand that there is considerable escalation in the Kansas State Ion Collision Physics Facility since last year. Is a handle being placed around that or brought under control?

Dr. **Trivelpiece**. With uncanny accuracy you have, of course, converged on one of those issues for which, yes, we are a bit embarrassed. There is adequate blame to go around. The costs were not accurately estimated the first time. We do believe we have them accurately organized at the moment and that the costs as indicated in the data sheets are accurate.

Mr. **Fuqua**. For the record, also, you might provide the committee with what you're doing to correct that situation.

Dr. **Trivelpiece**. Certainly.

[The information follows:]

The Department is committed to thoroughly review all aspects of projects including their cost, schedule, technical and management details prior to their inclusion in the budget. The experience at Kansas State University has sensitized us to look closely at all projects, regardless of dollar value, and early in the process provide them advice on design management and construction.

The procedure includes the following steps:

An approved Conceptual Design Report with cost and schedule is reviewed prior to budget consideration.

A validation review and approval by Headquarters and field personnel is required prior to budget consideration.

An approved Project Plan, Project Management Plan, and detailed cost estimate is required prior to project initiation.

Approval by DOE of preliminary designs is required before initiation of detailed design.

Approval by DOE of final design is required prior to the initiation of construction.

Monthly cost, schedule, and variance are reviewed by DOE.

Either quarterly or semiannual reviews of technical details, cost and schedule, and environmental aspects of the project are reviewed throughout the contruction period.

It is unfortunate that the situation at Kansas State has arisen but it has served to remind us that we must be on top of each of our projects at all times to insure the optimum use of Federal resources. We are now confident we have the situation at Kansas State under control and look forward to demonstrating that Kansas State is an exception and not the rule.

Mr. **Fuqua**. There's recently been a great deal of excitement about the SSC, the Superconducting Super Collider. Could you review that site selection process for us? Everywhere I go, including my own district, I get questions about that, and I'm sure the other members have a similar situation.

Dr. **Trivelpiece**. Yes, sir. As you're aware, Secretary Hodel is no longer Secretary of Energy and is now Secretary of the Interior. We have a new Secretary, Mr. Herrington. I have not yet had a chance to discuss in great detail the SSC activities, so in part what

I am saying reflects the carry-on of the activities that were organized when Don Hodel was Secretary.

The concern they had was that the process be orderly and fair, and a systematic approach to arrive at a point in which we would know what the technical issues were, how much it would cost, what it would take to do it, what the site criteria were going to be, and then, at that point, the Secretary would have to recommend to the President to include in the budget the necessary funds for construction, and that would be prior to the time that it would come to you.

Assuming that we arrived at the point in which the request for proposals was made from the Department——

Mr. FUQUA. That would be for sites?

Dr. TRIVELPIECE [continuing]. For sites. And that we received back a large collection of those proposals. And in the case of the activity that led up to the selection of Fermilab as the site for that accelerator, there were something in the order of 130 such proposals.

The first task is to examine them and determine whether or not they meet the prima facie requirements of the site criteria documents. So in sending out the request for proposals or whatever equivalent function there would be, there would be some stipulation it would have to meet certain criteria. That's an in-house review; we would carry out that and determine those that met the prima facie requirements of the RFP. Then that collection would be sent to the National Academy of Sciences, and in letters that I sent to Dr. Press and Dr. White—they are, respectively, the Presidents of the National Academy of Sciences and Engineering, and I will make those available for the record——

[The information follows:]

U.S. DEPARTMENT OF ENERGY
OFFICE OF THE PRESS SECRETARY
WASHINGTON, DC 20585

DOENEWS:

NEWS MEDIA CONTACT:
Phil Keif, 202/252-5730

FOR IMMEDIATE RELEASE
August 29, 1984

NOTE TO EDITORS:

Attached for your information is a letter from Dr. Alvin W. Trivelpiece, director of energy research for the Department of Energy, to Dr. H. Guyford Stever, president of Universities Research Association (URA), on the next step in the superconducting super collider (SSC) program. URA is the department's contractor for the design, research and development program on the SSC. Also attached are the memos enclosed with that letter, including one from Secretary of Energy Don Hodel giving approval to the pre-construction phase aimed at design and cost reduction for the superconducting magnet, the most essential and most costly parts of the SSC whose cost is estimated to be at least $3 billion. The Secretary said he could not commit the department to anything more than pre-construction efforts at this time. "Before proceeding further," he said, "we will need to be sure that all the components of the project -- scientific, financial, and institutional -- are firmly in place."

"I agree," Hodel wrote, "that this project is totally in the spirit of this Administration's commitment to the advancement of science and technology in the achievement of national goals. If our ultimate decision is to construct this machine, it will be a symbol of our dedication to scientific excellence."

The SSC would provide for collisions of two beams of positive (proton) particles at very high energies. There are other colliders for positive and negative particle beams, but none in which both particles are positive. High energy physicists consider the SSC an essential advancement in the ultimate understanding of force and matter.

The department expects to spend about $20 million on the SSC program during fiscal year 1985 which starts October 1, 1984.

-DOE-

N-84-047

AUG 16 1984

Dr. H. Guyford Stever
President
Universities Research Association (URA)
1103 Connecticut Avenue, NW
Suite 430
Washington, DC 20036

Dear Dr. Stever:

The enclosed memoranda from me to Secretary Hodel and his reply confirm that we have decided to proceed with the FY 1985 activities of the Superconducting Super Collider (SSC) project. In my memorandum to Secretary Hodel, I have summarized what has already been accomplished. You are to be commended for your role in guiding these activities that have provided the information that we needed to make our decision to proceed.

The SSC is an important project for the Nation and for the field of elementary particle physics. We want it to be initiated and managed in such a way as to give it the best possible chance for success. It is a large project, and it is necessary that we proceed in an appropriate step-wise manner during the Phase I efforts. This means meeting program goals and milestones and carefully planning for the next steps.

By beginning these FY 1985 activities, we are taking an important first step in an ambitious program that I hope will lead to the completion of the SSC project. This is a long term undertaking, and there will be many problems along the way. Patience and dedication to the goal will be required by everyone involved in this project. I look forward to working with you and the URA to make this a project that our Nation can be proud of.

Sincerely,

Signed

Alvin W. Trivelpiece
Director, Office of
Energy Research

Enclosures

United States Government

Department of Ene

memorandum

DATE: AUG 1 6 1984

REPLY TO
ATTN OF: S-1

SUBJECT: Superconducting Super Collider (SSC) Program

TO: Alvin W. Trivelpiece, ER-1

I appreciate the hard work that was done by you and your staff and many scientists and engineers throughout the country to prepare and review the SSC Reference Designs Study. This was a remarkable accomplishment, given the short time in which the work had to be done. The quality and content of the Study are excellent.

I agree that this project is totally in the spirit of this Administration's commitment to the advancement of science and technology as an essential ingredient in the achievement of national goals. If our ultimate decision is to construct this machine, it will be a symbol of our dedication to scientific excellence.

I expect you to continue to encourage international collaboration. In my discussion with leaders in Western Europe and Japan, the topic of how to handle large and costly scientific projects has invariably been raised for discussion. There is agreement that international collaboration is becoming increasingly important for projects such as the SSC.

I am pleased to concur with your plan to initiate the FY 1985 activities of the SSC program in the context of the phased plan described in your memorandum of August 10. However, I cannot commit the Department to the subsequent phases at this time. Before proceeding further, we will need to be sure that all the components of the project -- scientific, financial, and institutional -- are firmly in place.

Donald Paul Hodel
DONALD PAUL HODEL

United States Government Department of Energy

memorandum

DATE AUG 1 0 1984

REPLY TO
ATTN OF ER-1

SUBJECT INFORMATION: Superconducting Super Collider (SSC)

TO The Secretary

The agreed upon set of FY 1984 tasks associated with the proposed SSC project have been satisfactorily completed. Based on this, and a review of the overall project, I plan to approve starting the proposed FY 1985 activities on October 1, subject to the conditions outlined in this memorandum.

The completed FY 1984 tasks include:

1. The University Research Association (URA) has been selected as contractor for the design, research, and development program prior to the construction decision.
2. I have approved URA's selection of Dr. Maury Tigner as Director of the SSC design and R&D effort.
3. A Reference Designs Study, was done by a team of 150 specialists that included both contractor and industrial scientists and engineers. This study resulted in a cost estimate for the SSC of approximately $3 billion, in FY 1984 dollars, exclusive of site costs, detectors, computer capability, and start-up operations. The study also shows that no critical technology developments are required to build the accelerator.
4. An independent Office of Energy Research (OER) review of the Reference Designs Study has been conducted. It confirmed the cost estimates to within 10 percent.
5. The Reference Designs Study has also been reviewed by the Management and Administration (MA) Office of Project and Facilities Management. This review concludes that the most studied of the three design options could be constructed at a cost not more than 25 percent greater than that given by the Reference Designs Study.
6. The preliminary SSC management and program plans have been received.

I am greatly impressed with the thoroughness and dedication of everyone involved with these preliminary efforts. Their hard work and dedication underscores the importance of this project as an element in the Nation's and the world's science enterprise. I firmly believe that the SSC project is worth doing. It is completely consistent with this Administration's commitment to excellence in science and education. The SSC would be one of the unique and essential tools needed to make continued progress in our quest to understand the fundamental constituents of matter and the forces that influence their behavior.

The project will be managed in two main phases. Phase I refers to the research, development, and design activities prior to any construction. Phase II refers to actual construction. Phase I is further divided into subelements. Phase IA is defined to be the planned FY 1985 activities, and Phase IB is presently defined to be those activities in FY 1986 and beyond up to the start of construction.

The principal emphasis of Phase IA will be the research and development needed to select one of the three reference design magnet systems. The selected magnet system will be the object of Phase IB prototype development efforts. During Phase IA, additional design efforts will be conducted to improve cost estimates and identify areas where costs can be reduced further. A site criteria document will be prepared. Early in Phase IA, we will work with URA to refine the program and management plans to reflect adequately and accurately the goals, milestones, and controls needed by the Department to effectively guide this project.

I agree with your views on enhanced international collaboration. It should be promoted in this and other areas of science and technology where high-cost, unique facilities are required to do research. I am actively exploring possibilities for international collaboration in High Energy Physics through the Economic Summit Process, and through possible bilateral agreements with individual nations.

I want to stress that by starting these FY 1985 activities, the Department is not committed to subsequent activities. We plan to proceed in a step-wise manner through several phases with clear goals, milestones, and approval points along the way.

AW Trivelpiece

Alvin W. Trivelpiece
Director, Office of
Energy Research

U.S. DEPARTMENT OF ENERGY
OFFICE OF THE PRESS SECRETARY
WASHINGTON, DC 20585

DOENEWS:

NEWS MEDIA CONTACT:
Jeff Sherwood, 202/252-5806

FOR IMMEDIATE RELEASE
DECEMBER 14, 1984

NOTE TO EDITORS:

Attached for your information are letters from Dr. Alvin W. Trivelpiece, Director of Energy Research for the Department of Energy, to the Presidents of the Universities Research Association, the National Academy of Sciences and the National Academy of Engineering, establishing a site selection procedure for the proposed Superconducting Super Collider (SSC).

Also attached is an information memo by Dr. Trivelpiece outlining the elements of the process. Noting that although "no decision has been made to proceed with the construction of the SSC," Dr. Trivelpiece emphasizes that "it is important to establish the site selection procedure now, well in advance of when it might be needed, to help ensure an orderly site selection process and fair treatment for all interested parties."

The proposed SSC, a proton-proton collider, is a large basic research facility envisioned as the next logical step in facilities for the U.S. high energy physics program.

Universities Research Association is the department's contractor for the coordination of the R&D and conceptual design phase of the SSC.

-DOE-

N-84-065

Department of Energy
Washington, D.C. 20585

NOV 30 1984

Dr. Guyford Stever
President
Universities Research Association
Suite 430
1100 Connecticut Avenue, NW
Washington, DC 20036

Dear Dr. Stever:

As indicated in the enclosed copy of my information memorandum to Secretary Hodel, no decision has been made to proceed with the construction of the Superconducting Super Collider (SSC). Even so, I believe that it is important to establish the site selection procedure now, well in advance of when it might be needed, to help ensure an orderly site selection process and fair treatment for all interested parties.

The elements of this process are also outlined in the memorandum. One element is an independent review of the qualified proposals by a panel of distinguished individuals appointed by the Presidents of the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE). The role of this panel would be to select from among the qualified proposals those that are most excellent in terms of meeting the site criteria requirements and that offer the most outstanding opportunity to meet the needs of the Nation for this type of science facility.

It is important that those who are working on the SSC and other interested parties have a clear understanding of the site selection process that we would use. I would appreciate your making this information available to those with possible interest in the SSC.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

Enclosures

Department of Energy
Washington, D.C. 20585

NOV 30 1984

Dr. Frank Press
President
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, DC 20418

Dear Dr. Press:

The Department of Energy is sponsoring a program of research and development on the design of a future accelerator facility, the Superconducting Super Collider (SSC). This facility would be a world center for elementary particle physics. The construction costs for it are now expected to be about $3 billion (FY 1984 dollars), exclusive of costs for R&D, detectors, and site acquisition. The question of where this facility might be built is already attracting intense interest. Although the Department has not yet made a decision to proceed with the project, the process by which site selection for this facility would occur needs to be established now. The principal reasons are outlined in my memorandum to Secretary Hodel which is enclosed. The Department has already initiated the preparation of a site criteria document. This document, which is an essential first step in the overall process, outlines the requirements for the site that pertain to construction, operation, and proposal evaluation. After the Department has received, reviewed, and approved the site criteria document, it would be released to those interested in proposing a site for the SSC. This possible release assumes that the decision to proceed has been made.

Any proposals for the SSC sites received by the Department would be screened internally to determine if they meet the necessary requirements as stipulated in the site criteria document. Those qualified proposals that meet these conditions would then have to be reviewed to determine their overall excellence in meeting the needs of the Nation for an outstanding science facility.

It is in regard to the more detailed review of potential proposals that the Department would like to enlist the aid of the National Academy of Sciences and the National Academy of Engineering in the site selection process. Specifically, we would like the Presidents of the two Academies to jointly select a review panel of about fifteen distinguished individuals with appropriate experience. This panel would be expected to evaluate the qualified proposals against the site criteria requirements. They would then select a small group of those proposals that they believe to be most excellent in every respect and that best meet or exceed the various site requirements. The Panel Chairman would then inform the Director of the Office of Energy Research as to which proposals had been selected to be in this small group together with the Panel's summary of the basis for selection. The specific number of proposals that would be in this final unranked group cannot be foreseen at this time; however, it is expected that only a few of the most qualified would be included.

At such a time that the Department might receive proposals pursuant to the above described process, I hope that the Academies will agree to provide this assistance. A proper review of site proposals will be a critical element in the process of establishing the proposed SSC facility. It is essential that all institutions or organizations that compete for it be certain that they will receive fair and equitable treatment in all phases of an orderly selection process. The National Academy of Sciences and the National Academy of Engineering have impeccable reputations for fairness and objectivity. I am confident that the Academies' participation would provide a review of the proposals that meets the highest standards.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

Enclosure

Identical letter sent to:
Dr. Robert White, NAE

Department of Energy
Washington, D.C. 20585

NOV 3 0 1984

Dr. Robert M. White
President
National Academy of Engineering
2100 Pennsylvania Avenue, NW
Washington, DC 20037

Dear Dr. White:

The Department of Energy is sponsoring a program of research and development on the design of a future accelerator facility, the Superconducting Super Collider (SSC). This facility would be a world center for elementary particle physics. The construction costs for it are now expected to be about $3 billion (FY 1984 dollars), exclusive of costs for R&D, detectors, and site acquisition. The question of where this facility might be built is already attracting intense interest. Although the Department has not yet made a decision to proceed with the project, the process by which site selection for this facility would occur needs to be established now. The principal reasons are outlined in my memorandum to Secretary Hodel which is enclosed. The Department has already initiated the preparation of a site criteria document. This document, which is an essential first step in the overall process, outlines the requirements for the site that pertain to construction, operation, and proposal evaluation. After the Department has received, reviewed, and approved the site criteria document, it would be released to those interested in proposing a site for the SSC. This possible release assumes that the decision to proceed has been made.

Any proposals for the SSC sites received by the Department would be screened internally to determine if they meet the necessary requirements as stipulated in the site criteria document. Those qualified proposals that meet these conditions would then have to be reviewed to determine their overall excellence in meeting the needs of the Nation for an outstanding science facility.

It is in regard to the more detailed review of potential proposals that the Department would like to enlist the aid of the National Academy of Sciences and the National Academy of Engineering in the site selection process. Specifically, we would like the Presidents of the two Academies to jointly select a review panel of about fifteen distinguished individuals with appropriate experience. This panel would be expected to evaluate the qualified proposals against the site criteria requirements. They would then select a small group of those proposals that they believe to be most excellent in every respect and that best meet or exceed the various site requirements. The Panel Chairman would then inform the Director of the Office of Energy Research as to which proposals had been selected to be in this small group together with the Panel's summary of the basis for selection. The specific number of proposals that would be in this final unranked group cannot be foreseen at this time; however, it is expected that only a few of the most qualified would be included.

At such a time that the Department might receive proposals pursuant to the above described process, I hope that the Academies will agree to provide this assistance. A proper review of site proposals will be a critical element in the process of establishing the proposed SSC facility. It is essential that all institutions or organizations that compete for it be certain that they will receive fair and equitable treatment in all phases of an orderly selection process. The National Academy of Sciences and the National Academy of Engineering have impeccable reputations for fairness and objectivity. I am confident that the Academies' participation would provide a review of the proposals that meets the highest standards.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

Enclosure

Identical letter sent to:
Dr. Frank Press, NAS

NOV 30 1984

ER-1

INFORMATION: Superconducting Super Collider (SSC)

The Secretary

Although no decision has been made to proceed with the construction of the SSC, there are persuasive reasons why the process of site selection should be established now. The main reason is the intense interest in the possible location of the SSC. In the absence of a clear statement of the Department's plans, some of the interested parties may attempt to influence the choice of location prematurely.

We have already started the preparation of a site criteria document. It is being prepared by the technical design team formed by Universities Research Association (URA). It will describe the SSC in sufficient detail to cover all site-related aspects and define the site requirements that are to be met. This will include both those pertaining to construction and those related to eventual operation. The site criteria document will also specify the information required in site proposals to permit their proper evaluation.

After the site criteria document has been received by the Department, it will be reviewed in detail before any action is taken. If there is a decision to proceed with the project, then, at an appropriate time consistent with the Department's plans, the site criteria document would be made available to those parties interested in proposing a site for the SSC.

The proposals received by the Department would be given a preliminary evaluation to determine if they meet the site criteria requirements. Those proposals that do meet the site criteria conditions would then be reviewed by a select panel of appropriately qualified individuals appointed jointly by the Presidents of the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE).

This panel would identify a small number of the most excellent proposals. The panel chairman would then submit, unranked, their recommendations for this small group of proposals and the basis thereof, to the Director of the Office of Energy Research. Subsequent to this, the Department could select the SSC site from among this group if all the other conditions needed to proceed have been satisfied.

I believe that the process outlined above will maximize our chances of obtaining the best available site. Obviously, there are many steps that need to precede any decision to begin a site selection process. However, by announcing the process now, well in advance of when it might be needed, it will help ensure an orderly process and fair treatment for all interested parties.

Signed by Alvin W. Trivelpiece

Alvin W. Trivelpiece
Director, Office of
Energy Research

Attachments

Dr. **Trivelpiece** [continuing]. In these letters we asked them to, at such time as we should be in a position to proceed, to form a blue ribbon panel. That blue ribbon panel should then deliver back to us with their recommendations no more than a handful of proposals that they regard as exceeding in every sense the prima facie criteria, and being more or less equivalently excellent and capable of serving the Nation as the best possible facility. At that point it would be returned to the Department, and then I believe it would be a Secretarial recommendation and undoubtedly, for a project of this size, the concurrence of the President and proper notification of the Congress.

Mr. **Fuqua**. I notice that a lot of the States and local governments are starting to spend money to get proposals together and so forth. Is the Department encouraging them to do that at this particular time? And does that mean also that there is a possibility of proceeding with site selection in the immediate future? And I realize you need to discuss this with the Secretary, unless some procedure has been outlined already.

Dr. **Trivelpiece**. The last question first. We're not in a position to go forward with the site selection process at the moment. We aren't encouraging anyone at all; in fact, I think it's the contrary. We're trying to proceed in a stepwise manner to arrive at the point that it would be possible to make a recommendation as to whether or not to proceed. The fact that these various States and localities are doing this is beyond our control. In some cases it's beyond my comprehension, but it's a very interesting process to admire. I suspect it's the American way. It has kind of a frenzied attitude to it; I think if nobody had started it, probably everybody would be patient. I don't know who broke ranks first, but it's very clear that everybody is very eagerly setting out to acquaint the Department with the benefits of locating it in various regions.

Mr. **Fuqua**. Thank you.

Mr. Sensenbrenner.

Mr. **Sensenbrenner**. Thank you, Dr. Trivelpiece, for a very good opening statement. I just have one question.

Following up on the chairman's comment about the cost overrun at the Kansas State facility, do you have any idea what the cause of that overrun was?

Dr. **Trivelpiece**. Yes; it was probably some inattention to detail on our part; some misunderstanding on what it was that was being requested of Kansas State; some increase in the cost of the construction, I think, that they didn't accurately gauge. There are a collection of reasons, but probably no good excuses. I would be glad to supply the details of the reasons for the record, if you would appreciate that.

Mr. **Sensenbrenner**. I would appreciate that.

[The information follows:]

A review of the Kansas State University project, initially funded in the FY 1985 budget shows that a revised cost and schedule is required in order to carry out the scope as envisioned for the project. The project was proposed in the FY 1985 budget at a total estimated cost (TEC) of $3,400,000. The revised TEC is now estimated at $5,100,000.

A number of items account for the increase in TEC. By far the most compelling reason is that the design effort at the University has significantly progressed since the project was intitially proposed. This effort revealed the following:

A. Several project related costs were assumed to be funded from operating costs.

B. Equipment quotes from suppliers in several instances were greater than originally estimated.

C. A larger cryogenic system was determined to be required.

Kansas State University unreasonably assumed in the original proposal that operating funds would be provided to defray costs associated with research personnel time involved in the construction of the facility. In addition, it assumed that a computer necessary for the data acquisition at the facility would be provided at a later date. Based on our discussions with the University, we requested that this facility be viewed as a stand alone budget item. The University agrees with this budget approach and the estimate has been revised accordingly.

Insofar as the equipment item is concerned, the latest estimate reflects firm quotes for which we previously only had estimates. At this point, firm quotes are available for all systems to be procured from outside sources.

The last item accounting for the increase is the cryogenic system. A study by Kansas State of similar systems in other laboratories convinced them that the first cryogenic system proposed would result in a marginal operation. The new plan calls for incorporation of a large refrigerator easily capable of handling expected heat loads. The electronic system is also upgraded in order to match the data acquisition system based on the computer that was not in the original plan.

Mr. SENSENBRENNER. Of course, we're kind of crying over spilled milk, but I would hope that the system for future grants or future projects would be tightened up so that we don't have a repeat performance.

Dr. TRIVELPIECE. Mea culpa.

Mr. SENSENBRENNER. Thank you, Mr. Chairman.

Mr. FUQUA. Mr. Slaughter.

Mr. SLAUGHTER. Thank you, Mr. Chairman. I do have a question. Where does the CEBAF project stand on the list of priorities within the Department of Energy?

Dr. TRIVELPIECE. We have received a report from the Nuclear Sciences Advisory Committee in which they have reaffirmed that this is the highest priority item for the nuclear sciences community. We had requested a combination of construction and operating funds this year; however, in light of the budget deficit we are not proceeding with the construction. But in spite of that, we place a high enough priority on this that we did ask for a substantial sum of operating funds to get the project started to permit the SURA group to actively recruit and acquire a director and get some of the preliminary research and development done. We do expect, barring no difficulties, to proceed with the construction in fiscal year 1987.

Mr. SLAUGHTER. And that was $5 million for this year?

Dr. TRIVELPIECE. Yes; $5 million for this year.

Mr. SLAUGHTER. Have cost estimates changed on this project over the past year?

Dr. TRIVELPIECE. Not to my knowledge. It's $225 million in as expended dollars, or $201 million in fiscal year 1986 dollars, I believe is the current estimate.

Mr. SLAUGHTER. Thank you.

Mr. WALGREN (acting chairman). Anything further?

Mr. SLAUGHTER. No further questions.

Mr. WALGREN. The Chair would recognize Mr. Fawell.

Mr. FAWELL. I'm a new member of this committee, Doctor, so I can betray my ignorance very easily. But it appears from what figures I have that in terms of the overall fission energy reactor R&D budget this year, that the military portion is being increased by some 15 percent while the civilian budget is cut by about 11 percent. And parochially speaking, Argonne National Laboratory happens to be in my district and they are suffering an overall cut of around $46 million out of approximately $191 million, I think, that was budgeted to Argonne last year. So much so that the integral fast reactor R&D, I understand, is just obliterated.

Could you comment? Why the movements, evidently, toward the military, and then cuts in civilian R&D and then what seems to be a very detrimental effect on Argonne?

Dr. TRIVELPIECE. The Department of Energy is a large Department consisting of quite a few different elements. The total cashflow for it is around $21 billion, which is somewhat larger than you would gather in terms of its characteristics from looking at the—something like—$12 billion appropriation. But the function includes the cradle-to-grave responsibility for the nuclear weapons business and for civilian nuclear reactors, strategic petroleum reserves, and for basic research in the kinds of things that we're talking about here today.

In that complex collection of things, then, various national priorities come into play. And certainly, through the Stockpile Memorandum by which the President, the Department of Defense, and the Department of Energy come to an agreement on how many and what kind of nuclear weapons will be produced in the future and what kind of production materials are going to be needed, that determines the budget level and how many underground nuclear tests are required in Nevada. That collection of activities, then, is what has determined the military budget. So it is driven by the Stockpile Memorandum.

In the basic research areas, the fact that the administration has been strongly supportive of basic research has benefited some of the programs we're talking about here today, that we have tried to maintain current services in high energy physics and nuclear physics and most of the basic energy sciences.

In the areas that are more energy-intensive, such as the civilian nuclear activities and activities such as the fusion program, a freeze—minus some amount—was applied to those programs. Argonne is a laboratory that is concentrating some of its activities in the civilian nuclear activity, in the breeder activity. To the extent that those programs were reduced, then Argonne's budgets for those areas are reduced. My understanding is that Argonne is about $201 million,[1] which is down by an amount that just literally does reflect the reduction of civilian nuclear.

I don't have very much to do with establishing the priorities in the Civilian Nuclear Program. I do have the landlord responsibility for the Argonne National Laboratory and I am concerned, on the health and well-being of the Laboratory, that that reduction takes place; but it's the Assistant Secretary for Nuclear Energy who has the responsibility for that program.

Mr. FAWELL. I have been communicating with him, too. As I understand it, for instance, one of the new and most novel concepts, the integral fast reactor—the R&D is just gone. We no longer—if the budget cuts that are contemplated take place, we've lost that option as a practical matter. To cut $46 million out of the budget at Argonne—a lot of people in our area are deeply concerned that the institution itself is threatened, to have the advanced reactor funding go from $30 to $9 million, for instance, while by and large, those kinds of percentages of cuts—no one comes near receiving that kind of an impact. And Argonne also, for the last 5 years, has had a total loss of some $55 million net, while I think all of the other labs show gains.

---

[1] Subsequently changed by DOE to "179 million in fiscal year 1986."

So we're deeply concerned. If you might communicate with Mr. Vaughan, for instance, I would appreciate it very much. I would like perhaps to have a chance to talk with you in private about the matter, too.

Dr. TRIVELPIECE. I'd be delighted to do so.

Mr. FUQUA. Mr. Walgren.

Mr. WALGREN. Thank you, Mr. Chairman.

As you know, Dr. Trivelpiece, we've been trying to piece together some technological support for modernization in the steel industry from various places. Last year, I believe it was, Dr. Keyworth did plan at least a steel research program that was put in various places, including, as I understand it, the Office of Energy Research and the Basic Energy Science Program, to do some temperature work. Can you outline the status of that program? I understand it was not supported by OMB for fiscal 1986. Can you tell us what the Department of Energy is doing in that area for fiscal 1985 and what you would have hoped to do for 1986, and then what you can plan to do for 1986?

Dr. TRIVELPIECE. As you appreciate, there are certain constraints that are imposed on us by the appropriations accounts and how funds are appropriated and what they must be spent for. Within the limitations of the appropriations accounts for material sciences in 1985, and in 1984 as well, a certain portion of the activities that are supported in the BES Program in material sciences could be identified as being in support of these activities for the so-called steel initiative. We've continued that in 1985 at about the same level, and those activities don't require new funds. As you indicated, no new funds for 1986 have been requested, although I believe other discussions are taking place with regard to possibilities. If we were to make a major initiative in that area it would require either new funds or reprogramming because of the constraints that the appropriations requests impose on us.

But the idea is good, and the idea of trying to understand how going from ore to liquid, from liquid to near net shape, and how electromagnetic fields could be used to improve the efficiency of doing that—those are certainly energy-intensive things and science-intensive things for which some of the skills at the laboratory would be appropriately utilized. However, there are some minor difficulties in trying to bring that about in exactly the manner that had been envisioned by those who are desirous of doing it, and that includes me.

Mr. WALGREN. I'm sorry?

Dr. TRIVELPIECE. There are some difficulties. We are trying to make this happen, and to the extent possible within the limits imposed by spending funds in the manner for which they are appropriated, we are doing work at Argonne and Oak Ridge to try to bring some of that research about.

Mr. **Walgren**. Do you know, at this point, the level of the 1985 effort?

Dr. **Trivelpiece**. I would guess it's about a half a million dollars at the moment.

Mr. **Walgren**. Something in the range of $500,000?

Dr. **Trivelpiece**. Yes. They've spent $500,000, I think.

Mr. **Walgren**. Do you know—I was under the impression that the American Iron and Steel Institute had made some kind of contribution also. Is that factored into your understanding of that program?

Dr. **Trivelpiece**. They have, and I don't know the amount of that. I'm not quite sure how to answer the question in terms of taking it into account. Yes, it is certainly desirable to have that kind of research done with their collaboration through the laboratories. It is not something that we're in a position to make a matching fund arrangement with at the moment, under the constraints with which we have to operate.

Mr. **Walgren**. Prior to those restraints, what was the planning level of this initiative in the Department of Energy?

Dr. **Trivelpiece**. Well, I don't know that the Department had a plan, but the laboratories' plan that they had submitted to us was around $10 million.

Mr. **Walgren**. I see. And then, I understand, that was included in your recommendation to OMB but then, in OMB's review, that $10 million was dropped. Is that correct?

Dr. **Trivelpiece**. However the budget comes to its final form and appears to you, yes—it is not in there.

Mr. **Walgren**. Let me ask you this. Is the Office of Energy Research in this kind of particular program the most appropriate place within the Department of Energy for that kind of work, or are there other sites——

Dr. **Trivelpiece**. Well, it's one of two places that would make logical sense. The other place would be in the Conservation Program, and they have already supported contracts with a couple of steel companies on continuous strip casting for amounts that escape my memory at the moment, but I think they're in the $15 or $20 million category.

Mr. **Walgren**. So you think we're spending $500,000, and they had hoped to spend $10 million and were unable to get that past OMB?

Dr. **Trivelpiece**. Well, there wouldn't have been $10 million in 1985. If it had made it through the budget process, it might have been about that amount in 1986.

Mr. **Walgren**. What's the amount in 1985 that we are spending?

Dr. **Trivelpiece**. About $500,000, I believe.

Mr. **Walgren**. Well, we hope you can be supportive of that. I know Dr. Keyworth was in Iron Age Magazine as saying that they would "ensure that the Federal labs will be supportive to work on these projects." I think there is recognition of the importance of them at varying levels and, admittedly, in the process there's a tradeoff that has to be made. The value of the program, as I'm sure you understand, is widely appreciated, and it certainly seems something that would be a proper contribution for Government if we can make it.

Dr. **Trivelpiece.** I don't think the what is at serious issue. The how is perhaps a concern.

Mr. **Walgren.** OK.

Thank you, Mr. Chairman.

Mr. **Fuqua.** Thank you.

Mr. Packard.

Mr. **Packard.** Thank you, Mr. Chairman.

Dr. Trivelpiece, I'm sure you're aware that there are significant budget constraints that we're now being faced with and, for the last several years, there's been a constant increase and inflow of significant funding for good research projects. It's now a time, apparently, where we're going to have to evaluate and determine which projects ought to continue to be funded and, at the same time, recognize that new technology and new information needs to be researched.

How do you determine, and on what basis, are you and your Department now moving into that transitional period which we seem to be in, where we have to evaluate priorities in terms of keeping projects on line or whether to drop projects that have some benefits but, perhaps, do not weigh high in the priority list, and compare that with the funding of new concepts that need to be started? How do you do that?

Dr. **Trivelpiece.** With difficulty. [Laughter.]

It's not a new problem. If you look at a field such as high energy physics or nuclear physics and track it over a 15- or 20-year period, you find that 20 years ago most universities had state of the art accelerators. As the state-of-the-art required progressively more complex and costly facilities, then fewer universities had them and it was necessary to shut them down. As the frontier of science moved on it was necessary to have better facilities. As a result, we've ended up now, in the case of high energy physics, with 3 principal laboratories doing it and, instead of every university having its own accelerator, something like 100 universities come and take advantage of Fermilab, Stanford Linear Accelerator, or Brookhaven National Laboratory; or, for that matter, they go in some cases to overseas facilities if the research that they want to do is in that category. So it's a continual process of renewal, identifying where the frontier is, identifying the facilities that it takes to reach that frontier and penetrate it; and in the process we try to balance off the Government's resources that we have available within the Department, the requirements of the science as it is indicated to us from the scientific community, and to that extent we have a considerable amount of advice. Sometimes less than we need and sometimes more than we want, but it comes from committees such as the High Energy Physics Advisory Panel, the Nuclear Science Advisory Committee, and other committees of the Academy, the Energy Research Advisory Board—there is quite an adequate collection of inputs available to us to help us organize the scientific priorities. And as time passes, new fields become more interesting; and at the moment, things like biology are undergoing an explosion in terms of things that biologists know they can do that 10 years ago they couldn't do, that require facilities that are beginning to approach the kinds of costs that some of the nuclear facilities have had. And they would like to get in the game and make the kinds of contributions to basic science that have been coming out, make more contributions of that kind.

So it's just a difficult problem. It's going on all the time. Admittedly, we're currently going through a period in which the budget deficit is likely to constrain these things, and that will require a little bit more careful planning and perhaps some pruning of things that are not at the frontier.

As I say, we rely on a complex collection of inputs and try to do it in a balanced and fair way that preserves the core of excellence that the country needs.

Mr. PACKARD. Mr. Chairman, may I follow up with one short question?

Mr. FUQUA. Sure.

Mr. PACKARD. There are obviously, as you move through that process, worthy projects that have had continual research being done and funded, that need to be dropped out of the pipeline. What effort do you make to see that appropriate private sector industries pick up those projects and move forward with them if there's a need or desire to do so?

Dr. TRIVELPIECE. That's a short question that has a very long answer. Let me try to make a short answer to it.

The Department has a number of technology transfer activities that are formal in the sense that there are people designated at the laboratories to try to take the technology that is there and move it into the private sector intelligently and efficiently. On the other hand, as projects change, as scientists mature in their fields, as they find other interests, and so on, my experience is, from looking at that, is that one of the best technology transfer events that takes place is when a human being goes from one place to another with something good in his head. And as these projects ebb and flow, that the individuals move from one place to another; in some cases, they move into industry and they carry with them this kind of science and technology, or they serve as consultants. So the information does get out very effectively. And I think if you look at the—it's not so much—let me start back one more time. There is considerable criticism that we do not do enough to try to implement technology transfer. I think the record needs to be looked at in terms of just how well it has worked—the entire nuclear industry, the entire nuclear medicine industry, radiation processing of foods, and things like that are all examples of technology transfer, and those that I've picked tend to be out of the Department of Energy. So the technology transfer record is remarkable. At the same time, I know people are frustrated with the laboratories, the collection of activities, and would like to see more of it being done.

We could undoubtedly do more; I don't know exactly how we'd go about doing it, but I'd be glad to discuss it with you sometime more at length.

Mr. PACKARD. Thank you very much.

Mr. FUQUA. Mr. Mineta.

Mr. MINETA. Thank you very much, Mr. Chairman.

I'd just like to pick up on my colleague from California, Mr. Packard, as we talk about budget constraints.

It seems to me that, given budget constraints, what we're seeing—or the result—is a start and stop, start and stop, stretch out, whatever the phrase is, to keep things going. And I'm wondering whether or not we aren't barking up the wrong tree, whether we're not maybe doing things for the future based on what we've done in the past.

Maybe what we've got to do is say, "Look, maybe there's been too much centralization in some of these programs in terms of budgets," and we ought to give more flexibility to the national labs or whoever's out there doing this work. Let them make the decision, maybe, on what goes into operating and what goes into capital instead of us trying to fine-tune everything from a central perspective.

Now, I'm wondering whether or not you have maybe thought about or talked about some more flexible arrangement with our contracting agencies so that we don't really keep them so tightly harnessed so that they have no flexibility to wiggle? I'm wondering whether or not we shouldn't be giving a little more flexibility as an alternative to where we've been in the past.

Dr. Trivelpiece. There are several interesting answers to your question. One aspect of it is, I would certainly agree with you that the constraints of capital equipment, construction, and operating do produce problems, both for us and for the laboratories. That collection of constraints did not originate with the Department but, in fact, is a creature of the Congress.

There are some agencies who, in a sense, after the fact declare what construction and capital equipment they've done after making the appropriate management decisions on that. I would certainly support a relaxation of those boundaries or at least some flexibility in moving things from one place to the other, because there's no question it causes a problem.

There are times, of course, when some of the lab directors—who are here in the room—complain and cry about the lack of flexibility. There are times, on the other hand, that we are concerned that their flexibility causes us problems because they've done things in parallel with other laboratories that are perhaps not the best use of Federal resources. So it is a delicate balance, and whether or not they need more flexibility, could use more flexibility, whether we should have more flexibility, it's certainly an interesting debate. I don't know that things are that well centralized; I think there is quite a bit of flexibility in the system.

Mr. Mineta. We hear now there is, in a deregulatory environment, you know—management by objectives, regulations by objective, whatever the phrase might be, whatever the buzz word might be—I'm wondering whether or not maybe there ought not to be something in that order as an approach—I don't know, maybe you can't in scientific programs—but the other thing that concerns me, as I see this constraint from a budgetary consideration, costs going up, I also see maybe not underutilization, but less utilization of the facilities that are there and the tremendous investment that we have made. And that really bothers me. Then you tie into productivity and everything else. And again, that's another buzz word we've got today, productivity.

And so it seems to me, again, that we're short-changing ourselves all the way around.

Dr. **Trivelpiece**. Well, as I've appeared before this committee on several occasions in the past and other committees of Congress, I've tried to point out that it is appropriate that we try to support the investment in facilities that we've made by operating at a level consistent with that investment. And that's always a compromise between starting something new, stopping something old, operating the facilities at an appropriate level, providing the right collection of capital equipment. It's a complex process. I would not pretend that we have the perfect answer to it, but in the compromise mode we've tried to do the best we can.

But you asked the question on flexibility also, and it reminded me that earlier we were talking about the Kansas State situation in which the costs had grown a little bit. That's probably an example of where the flexibility works the other way. We do need to maintain some degree of management involvement in these activities in order to ensure that the Federal funds are expended in the appropriate manner; at the same time, give the necessary flexibility so that we're not managing the science. There's a difference between, mind you, managing programs and managing science. We have no business managing science, but we do have business in saying that two laboratories should not build simultaneously the same expensive facility to get the same result at the same time. That is a Federal responsibility. So if we gave them unfettered flexibility and they did that, I'm sure you would be asking questions of a more harsh nature on why we permitted that to occur. At the same time, there are circumstances in which, I think, we would like to give them more flexibility and are unable to do so by the constraints imposed on us.

Mr. **Mineta**. Well, I didn't intend it to be unfettered.

Dr. **Trivelpiece**. Well, in some cases the lab directors do. [Laughter.]

Mr. **Mineta**. Let me just very quickly ask a final question, and that is, given the nature of these projects getting to be more and more expensive, what about international collaboration? What are we doing in terms of trying to get multinational efforts going in certain things? You know, we visited—through the good graces of our chairman—CERN, seen what's going on there, but these are getting very, very expensive. What do you envision, let's say, at the next economic summit meeting? Is there any discussion that could be laid, or any groundwork that could be laid, on international collaboration?

Dr. **Trivelpiece**. There is quite a bit going on right now in conjunction with the economic summit. When Mr. Mitterrand—when the summit was in France, Mr. Mitterrand was the host. He suggested that science and technology be one of the areas to be emphasized. A working group was set up; some 18 areas were identified for possible enhanced collaboration. High energy physics and magnetic fusion were two of those. I'm chairman on the Summit Working Group for High Energy Physics and cochairman for the one on fusion. We met last year in Brussels following the London summit and set out a collection of tasks for people to conduct and report back to us in January. And we did meet in Cadarche in January and reviewed the progress that they had made, and this is in anticipation of a Technology Growth and Employment Report to the Bonn summit.

Essentially, what the meeting in Versailles laid out—or the meeting in Brussels laid out, and asked for the working groups to take on—was three things. No. 1, I call the wholesale problem; that is, several fields recognize that the next thing to do is likely to require a facility that is in excess of $1 billion. It is unrealistic to expect that several countries should simultaneously build the same facility to get the same result at the same time for things that cost in excess of $1 billion. Can we lay out an international coordinated plan whereby country A agrees to build thing 1, country B thing 2, and so on, in such a way that then there can be an exchange of scientists using these facilities? It doesn't necessarily mean that everyone goes out and puts all the money on the barrelhead and you build it in some third country, but in fact, an intelligent plan to agree not to do things simultaneously.

The other part of it, the retail business, is that currently we are spending a substantial quantity of money and, within that envelope of funds, are the things we can do jointly, sharing accelerators, sharing detectors, moving them around. The answer is yes, and it's probably pretty good right at the moment. The detectors have a life for high energy physics that goes far beyond, usually, the place where they were originally constructed and first used. Some of them from the United States have been moved to CERN, some have been moved to Japan; and the Japanese, at the moment—one of the pictures in your book there is a detector that the Japanese are building that will go in the new accelerator at Fermilab.

The other thing that came up at the Versailles process that for me was very interesting was what we call the "obstacles to international collaboration," administrative obstacles—such things as visas, customs regulations, the ability to have the unfettered use of wide band communications links, and so on. International agreements tend to inhibit the ability to have the things move smoothly. And you might ask one of the lab directors later on, because they have talked about the visa problem and how the visa problem restricts people getting back and forth, and what an impediment that is to international collaboration.

So we have a chance, through the Versailles process, to call attention to the heads of state what are the problems associated with international collaboration—what does it take to make it work. If they are serious that we should do it and that it would improve the economy, and science and technology is a part of it, they have a chance then to put their imprimatur on the kinds of recommendations that we're making. It's a slow process; it's not one that you can instantaneously do, but what we're trying to do is put in place the mechanisms by which the kind of collaboration I think we would both agree is needed will begin to naturally take place beyond that which is already going on, and it is going on very well at the moment. The thought that there isn't much is not correct; it really is quite substantial.

[The information follows:]

Attached is a letter that Dr. Trivelpiece sent to a number of countries which invited their participation in the SSC Project. This is a good example of how the Office of Energy Research is trying to promote international cooperation.

Department of Energy
Washington, D.C. 20585

FEB 27 1985

Dr. H. Deyda
Basic Research and International
Cooperation
Federal Ministry for Research and
Technology
Heinemannstraze 2
5300 Bonn 2

Dear Dr. Deyda:

The United States has embarked on an R&D program to determine the costs and other requirements for a 20 TeVx20 TeV high luminosity proton-proton collider, which has been proposed as the next logical step in high energy physics facility capability. This proposed Superconducting Super Collider (SSC) would be available for experiments by scientists from throughout the world. In that regard, it would be desirable to have some participation in this early R&D effort by scientists and engineers from those countries that are likely to be involved in the use of the facility. By such participation they would be better informed as to what form of collaboration might best suit the future interests of their colleagues. In turn, we would benefit from their contribution to our R&D efforts to develop a plan for the best possible facility at the lowest possible cost.

To this end, I am inviting you to suggest individuals who you would find advantageous to have involved in this R&D effort. There are some obvious administrative details that would need to be resolved, but I am sure these can be handled. I suggest that contact be made directly with Dr. Maury Tigner, Director of the Central Design Group (CDG) at Lawrence Berkeley Laboratory, regarding participation of specific individuals. I would appreciate any comments on the merits of this participation or how we might better go about establishing appropriate early collaboration in this proposed facility.

Sincerely,

Alvin W. Trivelpiece
Director, Office of
Energy Research

cc: J. Leiss, DOE
G. Stever, URA
M. Tigner, CDG/LBL

Similar letters sent to:

Dr. Jules Horowitz
Director
Institute for Fundamental Research
CEN-Saclay
91191 Gif-Sur-Yvette CEDEX
France

Dr. Paolo Fasella
Director-General
Commission of the European
Communities
Rue de la Loi 200
B-1049 Brussels, Belgium

Dr. Nicola Cabibbo
President, National Institute of
Nuclear Physics (INFN)
Piazza di Caprettari, 70
00186 Roma, Italy

Dr. Tetsuji Nishikawa
Director General
National Laboratory for High
Energy Physics
(KEK) MONBUSHO
1-1, Uehara, Oho-Machi
Tsukuba-gun
Obarago-ken 305
Japan

Dr. Harry Atkinson
Director, Science
Science and Engineering Research
Council
Polaris House
North Star Avenue
Swindon SN2 1ET
Wiltshire, United Kingdom

Dr. Douglas Stairs
McGill University
Rutherford Physics Building
3600 University Avenue
Montreal, Quebec H3A 2T8
Canada

Mr. **Mineta**. Thank you, Mr. Chairman.

Mr. **Fuqua**. Mr. Stallings.

Mr. **Stallings**. No questions.

Mr. **Fuqua**. Mr. Brown.

Mr. **Brown**. I have no questions, Mr. Chairman.

Mr. **Fuqua**. Mr. Cobey.

Mr. **Cobey**. No questions.

Mr. **Fuqua**. Mr. Bruce.

Mr. **Bruce**. No questions.

Mr. **Fuqua**. Thank you very much for joining us this morning. We appreciate you being here. There may be some additional questions that we have for the record that we will submit to you later.

Dr. **Trivelpiece**. Thank you, Mr. Chairman.

Mr. **Fuqua**. Thank you very much.

I might say, for the benefit of the members, in looking at the witness list and looking around the room, I am reminded of a story that President Kennedy said one night when he had the Nobel Prize winners there for dinner. He said it was probably the greatest assemblage of brain power since Thomas Jefferson dined alone. [Laughter.]

I'm not sure Thomas Jefferson ever dined in this room, but we are very impressed with the people we have here today. Thank you for being here this morning, Dr. Trivelpiece.

Dr. **Trivelpiece**. Thank you.

[Questions and answers for the record:]

QUESTIONS CONCERNING THE DEPARTMENT OF ENERGY'S FY 1985 SUPPORTING RESEARCH AND TECHNICAL ANALYSIS BUDGET REQUEST

BASIC ENERGY SCIENCES (BES)

General

1. For FY 1985 and FY 1986, please provide, by BES subprogram, actual and estimated operating expenses, capital equipment, and construction funding.

Answer: Please see the table below for the requested information.

BASIC ENERGY SCIENCES
(Dollars in thousands)

	FY 1985	FY 1986
Materials Sciences		
Operating Expenses	$133,055	$138,496
Capital Equipment	15,450	15,450
Construction	43,620	28,995
Subprogram Total	192,125	182,941
Chemical Sciences		
Operating Expenses	79,495	79,495
Capital Equipment	8,840	8,840
Construction	6,050	5,830
Subprogram Total	94,385	94,165
Nuclear Sciences		
Operating Expenses	40,350	43,338
Capital Equipment	2,950	2,754
Construction	300	1,300
Subprogram Total	43,600	47,392
Applied Mathematical Sciences		
Operating Expenses	35,074	28,020
Capital Equipment	1,500	1,070
Subprogram Total	36,574	29,090
Engineering and Geosciences		
Operating Expenses	26,675	26,675
Capital Equipment	1,500	1,500
Subprogram Total	28,175	28,175
Advanced Energy Projects		
Operating Expenses	10,602	10,602
Capital Equipment	320	320
Subprogram Total	10,922	10,922
Biological Energy Research		
Operating Expenses	12,455	12,455
Capital Equipment	560	560
Subprogram Total	13,105	13,015
Program Direction		
Operating Expenses	3,765	4,100
Subprogram Total	3,765	4,100
Basic Energy Sciences	$422,561	$409,800

2. **For FY 1985 and FY 1986, please provide, by DOE laboratory, actual and estimated BES funding going to DOE laboratories.**

Answer: Please see the table below for the requested information.

BASIC ENERGY SCIENCES
(Dollars in thousands)

	FY 1985	FY 1986
Operating Expenses		
Ames Laboratory	$ 11,330	$ 11,138
Argonne National Laboratory	37,740	38,500
Bartlesville Project Office	177	177
Brookhaven National Laboratory	45,699	48,700
Idaho National Engineering Laboratory	2,586	2,625
Lawrence Berkeley Laboratory	29,062	28,690
Lawrence Livermore National Laboratory	10,515	10,040
Los Alamos National Laboratory	10,244	11,000
Mound Laboratory	1,002	790
Oak Ridge National Laboratory	51,288	54,100
Pacific Northwest Laboratory	4,638	4,044
Pittsburgh Energy Technology Center	87	87
Princeton Plasma Physics Laboratory	708	708
Sandia National Laboratories, Albuquerque	6,000	6,808
Sandia National Laboratories, Livermore	7,235	7,300
Solar Energy Research Institute	1,424	1,239
Stanford University (SLAC)	25	50
Capital Equipment		
Ames Laboratory	1,315	1,285
Argonne National Laboratory	6,970	6,359
Bartlesville Project Office	20	21
Brookhaven National Laboratory	3,620	3,931
Idaho National Engineering Laboratory	139	112
Lawrence Berkeley Laboratory	4,406	3,126
Lawrence Livermore National Laboratory	1,275	750
Los Alamos National Laboratory	1,711	1,664
Mound Laboratory	81	58
Oak Ridge National Laboratory	5,688	4,978
Pacific Northwest Laboratory	517	456
Pittsburgh Energy Technology Center	10	10
Sandia National Laboratories, Albuquerque	665	707
Sandia National Laboratories, Livermore	850	750
Solar Energy Research Institute	216	149
Construction		
Ames Laboratory	500	600
Argonne National Laboratory	3,200	3,000
Brookhaven National Laboratory	11,700	8,995
Lawrence Berkeley Laboratory	10,790	17,440
Oak Ridge National Laboratory	500	1,200
Sandia National Laboratories, Livermore	100	300

3. **For FY 1985 and FY 1986, please provide BES subprogram, actual and estimated BES funding going to university researchers.**

Answer: Please see the table below for the requested information.

BASIC ENERGY SCIENCES
(dollars in thousands)

	FY 1985	FY 1986
Universities		
Nuclear Sciences..............	9,146	10,550
Materials Sciences.............	48,802	29,260
Chemical Sciences..............	25,157	25,300
Engineering & Geosciences......	10,057	10,000
Advanced Energy Projects.......	4,222	4,200
Biological Energy Research.....	8,567	8,600
Applied Mathematical Sciences..	17,629	10,400

4. **For FY 1985 and FY 1986, please provide, by entity, actual and estimated BES funding going to non-DOE laboratory, non-university entities, including industrial firms.**

Answer: Please see the table below for the requested information.

BASIC ENERGY SCIENCES
(Dollars in thousands)

Operating Expenses	FY 1985	FY 1986
Aerodyne Research, Inc.	$ 93	$ 93
Aerospace Corporation......................	122	122
American Chemical Society..................	10	10
American Institute for Biological Sciences.	50	50
American Society for Microbiology..........	8	0
Battelle Columbus Laboratory...............	221	231
Battelle - C. F. Kettering Research Laboratory................................	149	155
Bend Research, Inc.	693	693
Boeing Aerospace Company...................	85	85
Calspan Corporation........................	68	68
Carnegie Institute of Washington...........	6	0
Corning Glass Works........................	190	190
Dynatech R/D Company.......................	200	200
EIC Laboratories...........................	100	100
Electrochemical Tech. Corp.	93	0
Energy Technology Conf., Inc.	15	15
Flow Industries, Inc.	160	120
GA Technologies, Inc.	113	0
Geochem Research...........................	100	0
Government Institutes, Inc.	16	13

	FY 1985	FY 1986
Martin Marietta Corp.	95	55
Mathematical Sciences, NW	150	150
Membrane Tech. & Research, Inc.	141	400
National Academy of Sciences	339	335
National Tech. Systems	300	300
Owens Illinois, Inc.	75	75
Physical Sciences, Inc.	155	114
Physics International	200	200
Radiation Monitoring Devices	100	100
Rockwell International Corp.	110	0
Science Applications	176	205
SKF Industries	80	80
Smithsonian Inst., Astro Lab.	105	105
Smithsonian Institution	59	62
Society Indust. Appl. Math.	37	20
Soruce Technology	200	200
Southwest Research Institute	148	148
SRI International	576	582
Tetra Corporation	278	278
Hokenson Company	20	20
TRW, Inc.	267	0
Westinghouse R&D Center	100	100
Woods Hole Oceanographic Inst.	223	223
Woodward Clyde Consultants	100	100

5. **For FY 1985 and FY 1986, please provide, by user facility, actual and estimated operating expenses, capital equipment, and construction BES funding going to support user facilities.**

Answer: Information is being provided on 12 facilities in the BES program. This information is broken down into two groups. The first group includes BES Major Shared Access Research Facilities. They are as follows:

High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory
High Flux Beam Reactor (HFBR), Brookhaven National Laboratory
Intense Pulsed Neutron Source (IPNS), Argonne National Laboratory
Stanford Synchrotron Radiation Laboratory (SSRL), Stanford University
National Synchrotron Light Source (NSLS), Brookhaven National Lab.
Combustion Research Facility (CRF), Sandia National Lab.-Livermore

The second group includes other BES Collaborative-User Research Facilities. They are as follows:

High Voltage Electron Microscope Tandem Facility, Argonne National Lab.
National Center for Electron Microscopy (NCEM), Lawrence Berkeley Lab.
Spallation Neutron Research/Proton Storage Ring (SNR), Los Alamos National Laboratory
National Center for Small Angle Scattering Research, Oak Ridge National Laboratory
Oak Ridge Electron Linear Accelerator, Oak Ridge National Laboratory
Surface Modification and Characterization Laboratory (SMCL), Oak Ridge National Laboratory

Following is a table reflecting the FY 1985 and FY 1986 amounts for both groups of facilities.

Facilities	FY 1985	FY 1986
Group 1 Major Shared Access Research Facilities		
HFIR		
Operating Expenses	$10,100	$11,200
Capital Equipment	425	425
Construction	300	1,200
HFBR		
Operating Expenses	11,530	11,935
Capital Equipment	560	560
Construction	500	180
IPNS		
Operating Expenses	6,550	7,300
SSRL		
Operating Expenses	8,040	8,316
Capital Equipment	900	1,150
Construction	9,230	2,660
NSLS		
Operating Expenses	18,770	20,915
Capital Equipment	740	1,400
Construction	11,200	8,815
CRF		
Operating Expenses	5,715	5,615
Capital Equipment	700	600
Construction	0	300
Group 2 Other BES Collaborative-User Research Facilities		
HVEM Tandem		
Operating Expenses	1,720	1,750
Capital Equipment	950	1,000
NCEM		
Operating Expenses	2,200	2,200
Capital Equipment	300	400
SNR		
Operating Expenses	2,000	2,500
Capital Equipment	500	600
NCSASR		
Operating Expenses	200	300
ORELA		
Operating Expenses	3,305	3,305
Capital Equipment	500	450
SMCL		
Operating Expenses	1,000	1,000

6. **Please provide, by user facility, utilization figures for FY 1985 and FY 1986. What would be an optimal level of utilization of each of the user facilities, and what level of funding would be required at each of the user facilities in FY 1986 to achieve this optimal level of utilization?**

Answer:

ORNL

- National Center for Small-Angle Scattering Research

  This facility will operate at 100% utilization in FY 1985 and FY 1986. The neutron scattering (funded by NSF) research portion of the facility will operate at optimal utilization while the X-ray scattering research portion (funded by DOE) will require approximately $200,000 to achieve optimal utilization (an increase of $100,000).

- Surface Modification and Characterization Facility

  This facility will operate at approximately 100% utilization in FY 1985 and at about 80% utilization in FY 1986. The FY level of funding required to achieve optimal utilization is $1,200,000 (an increase of $250,000).

- Shared Research Equipment Program (SHARE)

  The utilization of the collection of equipment included in the SHARE program for FY 1985 and the proposed FY 1986 utilization will be approximately 80%. The FY 1986 level of funding required to achieve the optimal level of utilization is about $375,000 (an increase of $75,000).

- High Flux Isotope Reactor (HFIR)

  The HFIR will operate at approximately 90% utilization for FY 1985 and FY 1986. This means that $6,500,000 operating funds and $1,300,000 fuel inventory funds will allow 90% operation in FY 1985. The FY 1986 funding proposed is $8,000,000 and a fuel inventory level of $900,000 for 90% utilization. An increase of $1,000,000 is needed to achieve 100% utilization.

  The neutron scattering research component at HFIR will operate at approximately 83% utilization in FY 1985 and approximately 78% in FY 1986. The FY 1986 level proposed is $2,370,000 and $520,000 additional funds would be required for optimal utilization in terms of research personpower.

BNL

- High Flux Beam Reactor (HFBR)

  The HFBR will operate at approximately 76% utilization for both FY 1985 and FY 1986. Resources will be made available to keep the reactor operating this fraction of the time except for maintenance and fuel loading periods. The FY 1986 level of operations funding needed to achieve the optimal level of utilization is $8,675,000 (an increase of $175,000).

- National Synchrotron Light Source (NSLS)

  The utilization of NSLS for FY 1985 is 79% and the proposed level for FY 1986 will be about 85%. The plan is to make available photons at both rings in FY 1985 and FY 1986. The FY 1986 level of operations funding needed to achieve the optimal level of utilization is $17,875,000 (an increase of $1,075,000) including research and development activities. In order to permit this reasonable level of operation time in FY 1986, some ongoing R&D and maintenance will be deferred within the proposed budget.

ANL

- Intense Pulsed Neutron Source (IPNS)

  The IPNS facility will operate at approximately 58% utilization for both FY 1985 and FY 1986. To achieve optimal utilization in FY 1986, the level of funding required is about $6,100,000 (an increase of $1,100,000)

- Electron Microscope Center (EMC)

  The EMC facility will operate at approximately 80% utilization in both FY 1985 and FY 1986. To achieve optimal utilization in FY 1986, the level of funding required is about $1,300,000 (an increase of $150,000).

LBL

- National Center for Electron Microscopy (NCEM)

  The NCEM facility would operate at approximately 60% utilization in FY 1985 and will be reduced to 55% utilization in FY 1986. To achieve optimal utilization in FY 1986, the level of funding required is about $1,900,000 (an increase of $500,000).

LANL

- Spallation Neutron Research/Proton Storage Ring

  The SNR/PSR facility will operate at approximately 12% utilization in FY 1985 and in FY 1986. With the PSR becoming operational in mid-FY 1985, optimal utilization in FY 1986 would require $4,390,000 (an increase of $3,690,000).

Sandia

- Combustion Research Facility (CRF)

  The current utilization rate at the Combustion Research Facility is 96%. In FY 1986 under the current budget request utilization is projected to be 78%. In order to achieve full utilization by visiting scientists working alongside CRF's scientists, the funding of facility operation and visitor support would have to be increased by $900,000 to $4,275,000.

Stanford

- Stanford Synchrotron Radiation Laboratory (SSRL)

  In terms of 8 hour shifts, FY 1985 utilization of the Stanford Synchrotron Radiation Laboratory is 88%, but shortage of support staff makes those 8 hour shifts about 15% less effective due to added time required for users to become oriented, safety-checked, etc. In FY 1986 utilization is expected to be only 64%. It would require an additional $1,900,000 to achieve full utilization.

7. **For FY 1985 and FY 1986, please provide, by agency, the amount of BES funding going to support BES research at other agencies.**

Answer: Please see table below for requested information.

BASIC ENERGY SCIENCES
(Dollars in thousands)

	FY 1985	FY 1986
Agriculture, U.S. Dept. of...............	$ 45	$ 45
NASA....................................	202	0
National Bureau of Standards:............	2,712	2,742
National Science Foundation..............	55	30
National Institutes of Health............	40	40
Naval Research Laboratory................	0	150

8. **For FY 1985 and FY 1986, please provide, by BES subprogram, estimated funding from other agencies to support BES research.**

Answer: For FY 1985 and FY 1986 BES did not receive, and does not plan to receive, any funding from other agencies to support BES research.

9. **For FY 1985 and FY 1986, please provide, by nation, (a) actual and estimated funding going to support BES research at foreign institutions. and (b) actual and estimated funding or other support received from other nations for BES research.**

Answer: (a) For FY 1985 and FY 1986 BES did not have, and does not plan to have, any research grants or contracts with foreign institutions.

(b) The BES program has only one international agreement for which funding is formally sent to the Department via a deposit into a Treasury account. This agreement is with Japan and involves joint neutron scattering research at ORNL and BNL. The estimated funding provided by Japan for FY 1985 and FY 1986 is as follows:

Year	Budget Authority
1985	$200,000
1986	$220,000

10. **How much did the BES Program contribute to the support of DOE's Small Business Innovative Research (SBIR) Program for FY 1984? How much is estimated for FY 1985 and FY 1986?**

Answer: In FY 1984 BES contributed $1,740,000 to the support of DOE's Small Business Innovative Research (SBIR) Program. In FY 1985 $3,350,000 has been contributed to SBIR and in FY 1986 $3,291,000 's estimated for SBIR.

11. The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the BES program totalled $517.0 million, including $423.1 million for operating expenses and $93.9 million for plant and capital equipment. According to these Tables, the Department's FY 1986 submission to OMB totalled $482.1 million, including $397.7 million for operating expenses and $84.4 million for plant and capital equipment. What are the specific differences between these two budgets?

Answer: Please see the table below and explanation that follows for the differences between the FY 1986 IRB and the FY 1986 OMB Budget.

(Dollars in thousands)

	FY 1986 IRB Request	FY 1986 OMB Request	Change
Basic Energy Sciences (BES)			
Materials Sciences			
Operating Expenses.......	$156,776	$153,970	$- 2,806
Capital Equipment........	17,200	17,318	+ 118
Construction.............	43,195	35,995	- 7,200
Subtotal................	217,171	207,283	- 9,888
Chemical Sciences			
Operating Expenses.......	93,268	86,424	- 6,844
Capital Equipment........	10,350	10,340	- 10
Construction.............	10,130	9,630	- 500
Subtotal................	113,748	106,394	- 7,354
Nuclear Sciences			
Operating Expenses.......	58,301	48,212	-10,089
Capital Equipment........	4,325	2,754	- 1,571
Construction.............	1,300	1,300	0
Subtotal................	63,926	52,266	-11,660
Applied Mathematical Sciences			
Operating Expenses.......	60,700	52,900	- 8,140
Capital Equipment........	4,200	4,200	0
Subtotal................	64,900	57,100	- 8,140
Engineering and Geosciences			
Operating Expenses.......	22,338	28,213	+ 5,875
Capital Equipment........	1,675	2,000	+ 325
Subtotal................	24,013	30,213	+ 6,200
Advanced Energy Projects			
Operating Expenses.......	11,184	11,184	0
Capital Equipment........	330	330	0
Subtotal................	11,514	11,514	0
Biological Energy Research			
Operating Expenses.......	15,300	13,000	- 2,300
Capital Equipment........	1,200	500	- 700
Subtotal................	16,500	13,500	- 3,000
Program Direction			
Operating Expenses.......	5,225	4,170	- 1,055
Subtotal................	5,225	4,170	- 1,055
Total			
Operating Expenses.......	423,092	397,733	-25,359
Capital Equipment........	39,280	37,442	- 1,838
Construction.............	54,625	46,925	- 7,700
Basic Energy Sciences........	$516,997	$482,100	$-34,897

Explanation of Budget Changes

General

- Budget changes the result of meeting OMB target levels. By subprogram the OMB budget reflects the following changes:

Materials Sciences

- A deferral of a portion of the research thrusts proposed in advanced polymers and novel ceramics.
- A deferral of the Neutron Scattering Experimental Halls (LANL) construction project.
- Later information that the Congress had provided total funding for the Catholic University project in FY 1985 and therefore additional funding being proposed for FY 1986 could be eliminated.

Chemical Sciences

- A deferral of research thrust in chemical reactivity and catalysis.
- A general reduction to proposed GPP funding level.

Nuclear Sciences

- A general reduction in the activities making up the Nuclear Sciences subprogram, including Nuclear Data, Heavy Ion Fusion, SSRL, Heavy Element Chemistry, and stable and special isotope Production.

Applied Mathematical Sciences

- Defers selected research in parallel algorithms and multiprocessor machines.

Engineering and Geosciences

- Permit high priority engineering research as proposed and appropriated by the Congress in FY 1985.

Advanced Energy Projects

- No change.

Biological Energy Research

- Defers research thrust in polysaccharides.

Program Direction

- Deferral of staff increases proposed above the FY 1985 level.

12. **As noted in question 11 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $482.1 million, including 397.7 million for operating expenses and $84.4 million for plant and capital equipment, and the FY 1986 Congressional request for BES totalled $409.8 million, including $343.2 million for operating expenses and $66.6 million for plant and capital equipment. (a) What was the original OMB passback? (b) What specific items much did the Department appeal to have included in the Congressional request that are not included in the Congressional request? (c) What are the specific differences between these two budgets?**

Answer: Development of the FY 1986 budget was not a traditional or formal process and involved many discussions and informal interim steps. Specific differences between the Basic Energy Sciences OMB and the Basic Energy Sciences Congressional budget requests are given below.

	(Dollars in thousands)		
	FY 1986 OMB Request	FY 1986 Cong. Request	Change
Basic Energy Sciences (BES)			
Materials Sciences			
Operating Expenses.........	$153,970	$138,496	$- 15,474
Capital Equipment..........	17,318	15,450	- 1,868
Construction..............	35,995	28,995	- 7,000
Subtotal..................	207,283	182,941	- 24,342
Chemical Sciences			
Operating Expenses.........	86,424	79,495	- 6,929
Capital Equipment..........	10,340	8,840	- 1,500
Construction..............	9,630	5,830	- 3,800
Subtotal..................	106,394	94,165	- 12,229
Nuclear Sciences			
Operating expenses.........	48,212	3,338	- 4,874
Capital Equipment..........	2,754	2,754	0
Construction..............	1,300	1,300	0
Subtotal..................	52,266	47,392	- 4,874
Applied Mathematical Sciences			
Operating Expenses.........	52,560	28,020	- 24,540
Capital Equipment..........	4,200	1,070	- 3,130
Subtotal..................	56,760	29,090	- 27,670
Engineering and Geosciences			
Operating Expenses.........	28,213	26,675	- 1,538
Capital Equipment..........	2,000	1,500	- 500
Subtotal..................	30,213	28,175	- 2,038
Advanced Energy Projects			
Operating Expenses.........	11,184	10,602	- 582
Capital Equipment..........	330	320	- 10
Subtotal..................	11,514	10,922	- 592
Biological Energy Research			
Operating Expenses.........	13,000	12,455	- 545
Capital Equipment..........	500	560	+ 60
Subtotal..................	13,500	13,015	- 485
Program Direction			
Operating Expenses.........	4,170	4,100	- 70
Subtotal..................	4,170	4,100	- 70
Total			
Operating Expenses.........	397,733	343,181	- 54,552
Capital Equipment.........	37,442	30,494	- 6,948
Construction.............	46,925	36,125	- 10,800
Basic Energy Sciences.......	$482,100	$409,800	$- 72,300

Explanation of Budget Changes

General

- Budget changes principally the result of meeting overall Administration budget targets in order to meet the objectives of the President's Deficit Reduction Program. By subprogram the Congressional budget reflects the following changes:

Materials Sciences

- Budget restricted to FY 1985 level except for critical increases needed for user facility operations. New research thrusts in polymers and ceramics postponed.
- Funding for Columbia University Project and CP-5 Containment Project (ANL) deferred.

Chemical Sciences

- Deferral of new research thrusts in chemical reactivity and catalysis and continued funding of base program at the FY 1985 level.
- Deferral of construction of Phase II of the Combustion Research Facility and continued funding of GPP at the FY 1985 level.

Nuclear Sciences

- Budget limited to FY 1985 level except for critical increases needed for facility operations. A general reduction was made in each of the activities making up the Nuclear Sciences subprogram.

Applied Mathematical Sciences

- Deferral of new research initiatives in parallel algorithms and multiprocessor machines.
- Deferral of continued funding for Supercomputer Center at Florida State.

Engineering and Geosciences

- Research effort held at the FY 1985 level.

Advanced Energy Projects

- Deferral of research above the FY 1985 level.

Biological Energy Research

- Deferral of research above the FY 1985 level.

Program Direction

- Minor decrease in funding for program direction.

13. Given the information in questions 11 and 12 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for BES?

Answer: Please see the table below and explanation that follows for the differences between the FY 1986 IRB and the FY 1986 Congressional request.

	(Dollars in thousands) FY 1986 IRB Request	 FY 1986 Cong. Request	 Change
Basic Energy Sciences			
Materials Sciences			
Operating Expenses........	$156,776	$138,496	$- 18,280
Capital Equipment.........	17,200	15,450	- 1,750
Construction..............	43,195	28,995	- 14,200
Subtotal..................	217,171	182,941	- 34,230
Chemical Sciences			
Operating Expenses........	93,268	79,495	- 13,773
Capital Equipment.........	10,350	8,840	- 1,510
Construction..............	10,130	5,830	- 4,300
Subtotal..................	113,748	94,165	- 19,583
Nuclear Sciences			
Operating expenses........	58,301	43,338	- 14,963
Capital Equipment.........	4,325	2,754	- 1,571
Construction..............	1,300	1,300	0
Subtotal..................	63,926	47,392	- 16,534
Applied Mathematical Sciences			
Operating Expenses........	60,700	28,020	- 32,680
Capital Equipment.........	4,200	1,070	- 3,130
Subtotal..................	64,900	29,090	- 35,810
Engineering and Geosciences			
Operating Expenses........	22,338	26,675	+ 4,337
Capital Equipment.........	1,675	1,500	- 175
Subtotal..................	24,013	28,175	+ 4,162
Advanced Energy Projects			
Operating Expenses........	11,184	10,602	- 582
Capital Equipment.........	330	320	- 10
Subtotal..................	11,514	10,922	- 592
Biological Energy Research			
Operating Expenses........	15,300	12,455	- 2,845
Capital Equipment.........	1,200	560	- 640
Subtotal..................	16,500	13,015	- 3,485
Program Direction			
Operating Expenses........	5,225	4,100	- 1,125
Subtotal..................	5,225	4,100	- 1,125
Total			
Operating Expenses........	423,092	343,181	- 79,911
Capital Equipment.........	39,280	30,494	- 8,786
Construction..............	54,625	36,125	- 18,500
Basic Energy Sciences.......	$516,997	$409,800	$-107,197

Explanation of Budget Changes

General

- Budget changes principally the result of meeting overall Administration budget targets in order to meet the objectives of the President's Deficit Reduction Program. By subprogram the OMB budget reflects the following changes:

Materials Sciences

- Budget restricted to FY 1985 level except for critical increases needed for user facility operations. New research thrusts in polymers and ceramics postponed.

- Funding for Columbia University Project, Neutron Scattering Experimental Halls, and CP-5 Containment Project (ANL) deferred.

Chemical Sciences

- Deferral of new research thrusts in chemical reactivity and catalysis and continued funding of base program at the FY 1985 level.

- Deferral of construction of Phase II of the Combustion Research Facility and continued funding of GPP at the FY 1985 level.

Nuclear Sciences

- Budget limited to FY 1985 level except for critical increases needed for facility operations. A general reduction was made in each of the activities making up the Nuclear Sciences subprogram.

Applied Mathematical Sciences

- Deferral of new research initiatives in parallel algorithms and multiprocessor machines.

- Deferral of Class VII computer system and postponement of continued funding for Supercomputer Center at Florida State.

Engineering and Geosciences

- Permit high priority research in engineering research as proposed and appropriated by the Congress in FY 1985.

Advanced Energy Projects

- Deferral of research above the FY 1985 level.

Biological Energy Research

- Deferral of research thrust in polysaccharides.

Program Direction

- Deferral of staff increases proposed above the FY 1985 level.

14. **How many researchers were supported or will be supported by the BES program in FY 1984, FY 1985 and FY 1985?**

Answer: The number of researchers supported by the BES program is estimated at approximately 2,170 in FY 1984, 2,300 in FY 1985, and 2,260 in FY 1986.

Materials Sciences

15. **The Department's FY 1985 request for the Advanced Materials Initiative included $12.55 million for "Programmatic Research and Research and Development Associated with Construction." What is the actual amount of FY 1985 funding now planned for this activity? Please describe in detail the plans for the use and distribution of those funds.**

Answer: The capital equipment plus operating total amount of FY 1985 funding planned for the Department's Advanced Materials Initiative is $9,250,000. The present distribution and use of these funds are:

(Dollars in Thousands)

	Operating Funds	Equipment Funds
SSRL	$1,140 (R&D associated with construction, $700, and Materials Sciences operation funding at SSRL, $440).	$ 750
LBL	$2,210 (generic R&D on advanced photon systems and beam lines including the optics center research).	700
LBL	$2,800 (continuation of Center for Advanced Materials research programs on ceramics, catalysis and surface instrumentation, electronic materials, and polymers).	1,100
BNL	$500 (R&D associated with construction of NSLS Phase II).	$ 0
Contract Research	$50 (workshop on scope of high energy synchrotron radiation facility).	0
	$6,700	$ 2,550

16. **What is the status of the National Synchrotron Light Source? Please provide a detailed account of the current situation at the x-ray ring.**

Answer: The National Synchrotron Light Source (NSLS) is currently operational for experiments at both the VUV ring and the X-ray ring. During the past year a committee appointed by DOE reviewed the progress and problems associated with machine operation and this Committee found no fundamental obstacles to achieving full design goals. The Committee had many useful recommendations which are being implemented. The NSLS was shut down for a lengthy period in the fall/winter of 1984 to undertake some modifications and maintenance, some of which are routine for an accelerator. The machine is now operational where a full productive experimental program has resumed at the VUV ring. Recently, 700 ma have been stored in the VUV ring which is a new high, and approaches the peak design of 1 ampere. At the X-ray ring, experimenters are aligning X-ray beams, monochromators, and mirrors. The first EXAFS experimental spectra was taken and electron energy in the X-ray ring has reached design goals of 2.5 GeV. Electron currents of up to 70 ma have been achieved in the X-ray ring, and electron lifetimes of more than 10 hours at 10 ma are now routine. It will take several more months of ring conditioning to achieve good experimental conditions. In short, the NSLS is operating well and is steadily being brought into more favorable operating conditions.

Applied Mathematical Sciences

17. **The budget justification for FY 1985 stated that one state-of-the-art supercomputer would be leased in FY 1985 to satisfy the computing requirements of the Energy Research programs. Has this computer been leased, and if so, what kind is it, where is it located, and what are the financial arrangements?**

Answer: A Cray-XMP/22 was acquired in November, 1984 and installed at the National Magnetic Fusion Energy Computer Center at Lawrence Livermore National Laboratory. The financial arrangements are a conventional three-year lease which can be terminated after two years with termination penalty of one month's lease ($314,000). This is intended to be an interim machine until a Class VII is selected through a fully competitive solicitation.

18. **What is the cost of the Class V computer for Argonne National Laboratory identified in FY 1986 budget request? How will the expense of the machine be allocated across the BES, High Energy Physics and Nuclear Physics programs?**

Answer: The purchase equivalent value of the Class V computer for Argonne National Laboratory is $4,600,000. This item will be acquired on a four-year lease to ownership arrangement and the FY 1986 operating expense cost is estimated to be $720,000. This machine will support a variety of DOE programs at Argonne and is only included in our budget because the Office of Energy Research has landlord responsibilities for Argonne. Costs will actually be charged to program users based upon usage.

Advanced Energy Projects

19. **How much of the FY 1986 budget request of $10.922 million is committed to ongoing projects, and how much is available for new starts in FY 1986?**

Answer: Projects in this program are generally limited to a maximum support period of about three years, and hence, there is a built in turnover of about one-third in the projects supported in any one year. Consequently, about one-third of the $10,922,000 requested, i.e., about $3,400,000 will be available to start about 14 new projects in FY 1986. The remainder, i.e., about $7,500,000 is committed to ongoing projects.

BES Construction

Kansas State University Ion Collision Physics Facility (Project 85-ER-403)

20. **Please provides the names and credentials of the design, construction, and operating management.**

Answer: The project is divided into two main activities. One is concerned with the LINAC (linear accelerator) and the other with CRYEBIS (cryogenic electron beam ion source). The organization consists of five main functions each headed by a different faculty member, all of whom report to the Principal Investigator, Professor Pat Richard. The names and credentials of these individuals and their areas of prime responsibility are as follows:

I. Design and construction of LINAC - Prof. Tom Gray, Ph.D., Florida State, 1967.

A structural draftsman with Biderman Engineering of Dallas, Texas 1956-57, a tool designer doing heavy aircraft tooling for General Dynamics, 1957-58 and professor of physics for 18 years. Built several large pieces of apparatus for research and has been closely involved with accelerator systems. Associated with the Kansas State accelerator laboratory since 1977. Designed, constructed and successfully operated a universally used source of hydrogen atoms. During his sabbatical leave this academic year, Dr. Gray spent four months at Florida State working on their LINAC system and is now at Argonne National Laboratory working on their LINAC system.

II. Design and construction of CRYEBIS - Prof. C. L. Cocke, Ph.D., Cal Tech, 1967.

Operated an experimental research program in atomic collisions since 1969. Supervised the design and construction of electron spectrometers, target chambers, x-ray spectrometers and associated beam line apparatus and electronics; as well as acquisition, installation and development of the nanosecond pulsing-bunching system for the KSU accelerator. Designed and supervised construction of several fast ion pumped recoil ion sources and computed the design of the ion optics, magnetic and electrostatic beam transport elements, electron guns, gun housing, high voltage platform and collector assemblies for the electron beam ion source. Familiar with other ongoing CRYEBIS efforts elsewhere.

III. Scientific and Engineering Support for LINAC and CRYEBIS

A. Cryogenics - Prof. John Eck, Ph.D., Johns Hopkins, 1967.

Extensive experience with and knowledge of cryogenic techniques. Familiar with commercially available cryogenic equipment and practices. Extensive involvement in the design of a large vacuum scattering chamber for ORNL's Holifield Heavy Ion Accelerator.

B. Electronics - Prof. James Legg, Ph.D., Princeton, 1962.

Extensive experience with on line laboratory dedicated computer systems and with data taking and data analysis and software development. Performs hardware maintenance on computer systems. Familiar with microprocessor control and configuring and installing of laboratory instrumentation.

C. Beam optics and transport - Prof. S. Hagmann, Ph.D., Koln, 1977.

Expert in collision dynamics of highly charged ion-atomic systems, high resolution spectroscopy, and electron spectrometer technology. Familiar with technology for the production of high accelerator particle beams. Extensive experience with design and installation of beam optics.

IV. Operating management - Prof. Pat Richard, Ph.D., Florida State, 1964.

Principal investigator of DOE operating contract since 1975, Director of Macdonald Laboratory since 1982, in charge of total operation of the laboratory and research program; supervised installation of a new ion source/pulsed beam bunching system and data acquisition computer system. Managed and supervised technical staff, student helpers, machine and electronics shops, secretarial staff and financial operation of DOE contract and the laboratory. Directed own research projects, built and operated several pieces of apparatus including x-ray and Auger spectrometers, scattering chambers, magnetic systems and position sensitive detectors. Extensive experience using accelerator laboratories at other installations in the U.S. and Germany.

21. **What is the degree of reliability of the current $5.1 million cost estimate?**

Answer: The DOE is very confident that the current estimate of $5,100,000 is the final estimate for the Kansas State University Ion Collision Physics Facility. The Department has conducted a detailed review of the latest plans for the project and all previous problems associated with the estimate have been resolved.

22. **Please detail the reasons for all cost overruns.**

Answer: A number of items account for the increase in TEC. By far the most compelling reason is that the design effort at the University has significantly progressed since the project was initially proposed. This effort revealed the following:

A. Several project related costs were assumed to be funded from operating costs.

B. Equipment quotes from suppliers in several instances were greater than originally estimated.

C. A larger cryogenic system was determined to be required.

Kansas State University assumed in the original proposal that operating funds would be provided to defray costs associated with research personnel time involved in the construction of the facility. In addition, it was assumed that a computer necessary for the data acquisition at the facility would be provided at a later date. Based on our review and discussions with the University, we requested that this facility be viewed as a stand alone budget item. The University agrees with this budget approach and the estimate has been revised accordingly.

Insofar as the equipment item is concerned, the latest estimate reflects firm quotes for which we previously only had estimates. At this point, firm quotes are available for all systems to be procured from outside sources.

The last item accounting for the increase is the cryogenic system. A study by Kansas State of similar systems in other laboratories convinced them that the first cryogenic system proposed would result in a marginal operation. The new plan calls for incorporation of a larger refrigerator easily capable of handling expected heat loads. The electronic system is also upgraded in order to match the data acquisition system based on the computer that was not in the original plan.

23. What are the anticipated facility operating costs?

Answer: The anticipated increase in annual operating costs due to this Project is estimated to be $600,000 (FY 1985 dollars). Since this new construction is an improvement to the existing facility currently operated at an annual cost of $605,000, the overall annual operating cost is projected to be $1,205,000 per year.

Columbia University National Center for Chemical Research (Project 84-ER-115)

24. What are the reasons the project has a cost overrun of $8.0 million during its first year?

Answer: The cost estimate for the project has been increased from the original amount due to a number of unforeseen conditions. These include the need to provide a new foundation for the Havemeyer lecture hall, inadequate cooling capacity in the central plant requiring provision of a new chiller and cooling tower as part of the Havemeyer Addition, asbestos removal, correcting structural steel deficiencies in Havemeyer Hall, and installation of sprinklers to comply with a forthcoming city requirement.

25. **Who in DOE is responsible for this project, and who at Columbia University is responsible for the project?**

Answer: The requested information is as follows:

Headquarters

Dr. Lewis E. Temple, Jr.
Acting Director, Construction, Environment
and Safety Division
Office of Energy Research

Field

Richard P. Stenzel
Supervisory General Engineer
Project Management and Engineering Division
Chicago Operations Office

Columbia University

Robert Broberg
Vice President for Facilities Management

26. **What management methods are being employed to assure there are no further overruns?**

Answer: The DOE has a number of procedures which are followed for all projects administered by the Department. These formal procedures along with frequent contact and working with the university should assure that no further overruns occur.

These procedures include:

- An approved Conceptual Design Report with cost and schedule is reviewed prior to budget consideration.
- A validation review and approval by Headquarters and field personnel is required prior to budget consideration.
- An approved Project Plan, Project Management Plan, and detailed cost estimate is required prior to project initiation.
- Approval by DOE of preliminary designs is required before initiation of detailed design.
- Approval by DOE of final design is required prior to the initiation of construction.
- Either quarterly or semiannual reviews of technical details, cost and schedule, and environmental aspects of the project are conducted by DOE.

27. Please present the names of the design and construction firms involved.

Answer: The requested information is as follows:

Davis, Brody Associates
100 East 42nd Street
New York, NY 10017

Robert Silmen Associates, P.C.
88 University Place
New York, NY 10003

R. G. Vanderweil Engineers, Inc.
38 Chauncy Street
Boston, MA 02111-2362

Amis Construction and Consulting Services
44 E. 32nd Street
New York, NY

Brian Smith, A.I.A., R.I.D.A.

Centerguard Associates
115 Bloomfield Avenue
Caldwell, NJ 07006

P.J. Science Construction Company
24 W. 40th Street
New York, NY 10018

28. What type of contracts have been negotiated for this project?

Answer: DOE, Chicago Operations Office, has executed a grant with Columbia University.

Catholic University of America Vitreous State Laboratory (Project 84-ER-114)

29. What is the status of this project?

Answer: Title I is slightly behind schedule with the drawings to be issued on March 11, 1985. The drawings will then be forwarded to Chicago Operations Office for review. The critical date is April 1, 1985, since that is the start of Phase I construction which includes site demolition, site utilities, site grading, building excavation, footings, foundation walls, waterproofing, and backfill. A meeting between the project team and the District of Columbia was held January 22, 1985. The District will require approximately three weeks from the time they receive the drawings until the excavation permit is issued.

Several long lead procurement items will be released in the near future. Those include the chillers, ice tanks, exhaust fans, boiler, and probably the precast concrete panels for the curtain wall. The reason for bidding the precast concrete panels so early is that the project needs to get on the waiting line for these panels. Although the attachment details will not be available, the bidders will be asked to provide a ceiling price quota based on the most current information. A future change order may be required to revise the attachment points. Although this is not going to guarantee us the best price to begin with, at least the panels will be delivered when needed which will avoid delay in project completion.

The Phase II package designs will be completed in mid-April 1985, and the bidding process initiated in May 1985. A milestone schedule and spending plan will be included with the first quarterly report. There will be a total of between 25-30 bid packages issued with the bulk (15-20) in Phase II.

30. **Who in DOE is responsible for this project and how often does that person visit the project site?**

Answer: The requested information is as follows:

Headquarters

Dr. Lewis E. Temple, Jr.
Acting Director, Construction, Environment
and Safety Division
Office of Energy Research

Field

Robert C. Selby, Director
Project Management and Engineering Division
Chicago Operations Office

Site visits are made quarterly.

31. **What is the schedule for the project?**

Answer: The schedule for the project is as follows:

Schematic Design - 11/15/84 (Actual)
Final Design Phase A (Foundations) - 3/8/85
Start Phase A Construction - 4/21/85
Final Design Phase B (Superstructure) - 5/6/85
Start Phase B Construction - 5/27/85
Complete Construction - 11/1/86

ENERGY RESEARCH ANALYSIS

32. **The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the Energy Research Analysis program totalled $3.95 million for operating expenses. According to these Tables, the Department's FY 1986 submission to OMB totalled $3.90 million. What are the specific differences between these two budgets?**

Answer: The difference between the FY 1986 IRB Request of $3,950,000 for Energy Research Analysis and the submission to OMB for $3,900,000 was due to the Department's method of rounding down to the nearest tenth of a million.

33. **As noted in question 32 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $3.9 million, and the FY 1986 Congressional request for Energy Research Analysis totalled $2.7 million. What are the specific differences between these two budgets?**

Answer: The difference between the FY 1986 Energy Research Analysis (ERA) budget submission to OMB for $3,900,000 and the Congressional request for $2,700,000 was the result of holding program funding to 10 percent less than the FY 1985 level. This reduction was based on the Administration's desire to reduce the Federal deficit. The effect of this reduction is a deferral of requested increased funding for program and technical assessments.

34. **Given the information in questions 32 and 33 above, what are the specific differences between the Department's FY 1985 IRB and the Congressional request budgets for Energy Research Analysis?**

Answer: The specific differences between the Department's FY 1986 IRB and the Congressional request budgets for Energy Research Analysis (ERA) are the two reductions: first, the reduction of $50,000 due to Department rounding practices; and second, the reduction of $1,200,000 to hold ERA funding to a level 10 percent below the FY 1985 level. The effect of this reduction is a deferral of requested increased funding for program and technical assessments.

UNIVERSITY RESEARCH INSTRUMENTATION

35. **The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the University Research Instrumentation program totalled $8.0 million for operating expenses. According to these Tables, the Department's FY 1986 submission to OMB totalled $6.0 million. What are the specific differences between these two budgets?**

Answer: The reduction of $2,000,000 reflects a decrease of approximately 9 instrumentation awards.

36. **As noted in question 35 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $6.0 million, and the FY 1986 Congressional request for University Research Instrumentation totalled $4.5 million. What are the specific differences between these two budgets?**

Answer: The reduction of $1,500,000 reflects a 10% reduction from the FY 1985 budget, and is a decrease of 5 awards from the OMB request.

37. **Given the information in questions 35 and 36 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for University Research Instrumentation?**

Answer: The reduction of $3,500,000 reflects a decrease of 12 instrumentation awards.

UNIVERSITY RESEARCH SUPPORT

38. **The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the University Research Support program totalled $15.73 million for operating expenses. According to these Tables, the Department's FY 1986 submission to OMB totalled $19.5 million, including $10.5 million for operating expenses and $9.5 million for plant and capital equipment. What are the specific differences between these two budgets?**

Answer:

	($ In Thousands) FY 1986 IRB Request	 FY 1986 OMB Request	 Change
University Research Support			
University/National Laboratory Cooperative Research			
Operating Expenses	$14,630	$ 9,250	$-5,380
Construction	0	9,000	+9,000
Subtotal	$14,630	$18,250	$+3,620
Energy Manpower Development			
Operating Expenses	$ 1,100	$ 1,250	$+ 150
Total URS	$15,730	$19,500	$+3,770

Operating Expenses

The $5,230,000 difference includes: 1) a reduction of $3,480,000 in the Laboratory Cooperative Research Activity, which includes a 33% decrease in the number of student/faculty research appointments, and does not provide for replacement of instrumentation used by faculty/students at two laboratories. Eliminates support for 2 high school science teacher improvement workshops at the laboratories. Eliminates support to initiate women/minority scientist/engineering research internships, and decreases support for Historically Black Colleges and Universities (HBCU) Cooperative Research, 2) elimination of increased funding for Low Enriched Uranium (LEU) analysis of technical, cost, and safety considerations and related safety studies ($1.9 million), and 3) increases Education and Training by $150,000 which supports an additional 10 Prefreshmen Engineering Program awards.

Construction

The increase of $9,000,000 would provide for partial support for a Graduate Research Laboratory for Science and Technology at Atlanta University.

39. **As noted in question 38 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $19.5 million, including $10.5 million for operating expenses and $9.0 million for plant and capital equipment, and the FY 1986 Congressional request for University Research Support totalled $9.7 million for operating expenses. (a) What was the original OMB passback? (b) What specific items much did the Department appeal to have included in the Congressional request that are not included in the Congressional request? (c) What are the specific differences between these two budgets?**

Answer: Development of the FY 1986 budget was not a traditional or formal process and involved many discussions and informal interim steps. Specific differences between the OMB request and the Congressional budget request are given below:

	($ in Thousands) FY 1986 OMB Request	FY 1986 Cong Request	Change
University Research Support			
University/National Laboratory Cooperative Research			
Operating Expenses	$ 9,250	$ 8,700	$- 550
Construction	9,000	0	-9,000
Subtotal	$18,250	$ 8,700	$-9,550
Energy Manpower Development			
Operating Expenses	$ 1,250	$ 1,000	$- 250
Total URS	$19,500	$ 9,700	$-9,800

Operating Expenses

In the Congressional Budget Submission three activities were decreased: 1) the University Laboratory Cooperative Research (student appointments) decreased by $450,000, 2) the Reactor Fuel Assistance activity decreased by $100,000 eliminating 3 reactor sharing awards and, 3) the Education and Training activity decreased by $250,000 which eliminates 5 Prefreshman Engineering Awards and 3 laboratory high school institutes.

Construction

The reduction of $9,000,000 eliminates support for a Graduate Research Laboratory for Science and Technology at Atlanta University.

40. **Given the information in questions 38 and 39 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for University Research Support?**

Answer:

	($ in Thousands) FY 1986 IRB Request	FY 1986 Cong Request	Change
University Research Support			
University/National Laboratory Cooperative Research			
Operating Expenses	$14,630	$ 8,700	$-5,930
Energy Manpower Development			
Operating Expenses	$ 1,100	$ 1,000	$- 100
Total URS	$15,730	$ 9,700	$-6,030

Operating Expenses

Maintains the number of research participants in the Laboratory Cooperative Research Activity at the FY 1985 levels. Eliminates support to initiate women/minority re-entry research internships ($-350,000) and reduces number of high school science teacher improvement workshops supported at laboratories ($-250,000). The change also eliminates increased funding for Low Enriched Uranium (LEU) analysis of technical, cost, and safety considerations and related safety studies ($1,900,000) and maintains the number of Prefreshmen Engineering Program (PREP) awards at FY 1985 levels ($-100,000).

ADVISORY AND OVERSIGHT PROGRAM DIRECTION

41. **The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for Advisory and Oversight Program Direction totalled $3.5 million for operating expenses. According to these Tables, the Department's FY 1986 submission to OMB totalled $3.2 million. What are the specific differences between these two budgets?**

Answer: The FY 1986 IRB request for Advisory and Oversight Program Direction was $3,500,000 compared to the OMB request of $3,200,000, a difference of $300,000. This line item is for salaries, benefits, and associated staff support costs for the Office of Field Operations Management, the Office of Program Analysis, the Science and Technology Affairs Staff, and related program and management support staff. The difference between the two budgets is a reduction of 4 full-time equivalents (FTE's) at $250,000 from 47 FTE's in the IRB request to 43 FTE's in the submission to OMB and reduced staff support costs of $50,000.

42. **As noted in question 41 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $3.2 million, and the FY 1986 Congressional request for Advisory and Oversight Program Direction totalled $2.9 million. What are the specific differences between these two budgets?**

Answer: The FY 1986 submission to OMB for Advisory and Oversight Program Direction was $3,200,000 compared to the Congressional request of $2.9 million, a difference of $300,000. The difference between the two budgets is twofold.

- Of the total difference, $195,000 is related to reduced personnel compensation requirements. Savings are to be achieved primarily through a change in the personnel mix resulting in a reduction in average salary and other compensation requirements and through the Presidentially proposed 5 percent decrease in salaries and benefits. The cost of an additional FTE above the OMB submission has been absorbed.
- The remaining difference of $105,000 is a reduction in staff support services, supplies, and materials.

43. Given the information in questions 41 and 42 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for Energy Research Analysis?

Answer: The FY 1986 IRB request for Advisory and Oversight Program Direction was $3,500,000 compared to the Congressional request of $2,900,000, a difference of $600,000 as follows:

- Personnel compensation requirements have been reduced by $445,000 due to a reduction of 3 FTE's from 47 FTE's in the IRB request to 44 FTE's in the Congressional submission, savings resulting from a change in personnel mix, and the impact of the Presidentially proposed 5 percent decrease in salaries and benefits.
- Staff support services, supplies, and materials have been reduced by $155,000. This includes such things as printing, publications, and other small purchases, and commercial timesharing for information systems.

MULTIPROGRAM LABORATORIES FACILITIES SUPPORT

44. The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the Multiprogram Laboratories Facilities Support program totalled $61.7 for plant and capital equipment. According to these Tables, the Department's FY 1986 submission to OMB totalled $73.0 million for plant and capital equipment. What are the specific differences between these two budgets?

Answer: The following table reflects the projects that were changed from the IRB Request to the OMB Submission.

Multiprogram Laboratories Facilities Support
($ in Thousands)

Project #	Title	FY 1986 IRB Request	FY 1986 OMB Request	Change
Multipurpose General Purpose Facilities				
Construction				
	On-going projects	$39,150	$37,350	$- 1,800
86-R-725	Environment monitoring system upgrade, ORNL........	1,350	1,250	- 100
86-R-726	Fire Protection Improvements, BNL..................	500	500	0
86-R-727	Upgrade fire protection, ORNL........................	1,400	1,800	+ 400
86-R-728	Water line replacement, ANL.........................	1,000	1,000	0
86-R-729	Upgrade steam distribution system, ORNL................	1,100	2,000	+ 900
86-R-730	Safety Improvements to Pajarito Road, LANL.........	500	0	- 500
86-R-731	Renovation of Applied Sciences Center, Ames.......	1,200	1,200	0

Project #	Title	FY 1986 IRB Request	FY 1986 OMB Request	Change
86-R-732	Addition to Central Research & Administration Bldg, LBL..	1,800	550	- 1,250
86-R-734	Addition to Applied Math Building, BNL...............	1,000	1,000	0
86-R-735	Engineering and Technical support facility, LBL.......	1,000	0	- 1,000
86-R-736	Electrical system rehabilitation and improvement, LBL............	1,300	1,700	+ 400
86-R-737	Utility restoration - piping system, ORNL.........	1,000	0	- 1,000
86-R-738	Electrical system rehabilitation, ANL.........	1,200	1,200	0
86-R-739	Multiprogram technical support facility, RL........	400	400	0
86-R-740	Science and Technology building, LLNL..............	3,100	0	- 3,100
86-R-741	Electrical and telecommunication system upgrade, INEL...............	1,900	0	- 1,900
86-R-742	Transportation complex, INEL.......................	2,000	0	- 2,000
86-R-743	Site entrances improvements, LLNL..........	800	0	- 800
86-R-744	Mechanical system rehabilitation, ANL.........	0	750	+ 750
	Subtotal	61,700	50,700	-11,000
Environmental Compliance				
Operating Expenses		0	13,300	+13,300
Capital Equipment		0	1,000	+ 1,000
Construction		0	8,000	+ 8,000
Subtotal		0	22,300	+22,300
Total MLFS		$61,700	$73,000	$+11,300

45. As noted in question 44 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $73.0 million for plant and capital equipment, and the FY 1986 Congressional request for Multiprogram Laboratories Facilities Support totalled $51.2 million, including $12.9 million for operating expenses and $38.3 million for plant and capital equipment. (a) What was the original OMB passback? (b) What specific items much did the Department appeal to have included in the Congressional request that are not included in the Congressional request? (c) What are the specific differences between these two budgets?

Answer: Development of the FY 1986 budget was not a traditional or formal process and involved many discussions and informal interim steps. The following table reflects the projects that were changed from the OMB Request to the Congressional Submission.

Multiprogram Laboratories Facilities Support
($ In Thousands)

Project #	Title	FY 1986 OMB Request	FY 1986 Cong Request	Change
Multipurpose General Purpose Facilities				
Construction				
	On-going projects........	$37,350	$28,800	$- 8,550
86-R-725	Environment monitoring system upgrade, ORNL.....	1,250	0	- 1,250
86-R-726	Fire Protection Improvements, BNL...............	500	500	0
86-R-727	Upgrade fire protection, ORNL.....................	1,800	0	- 1,800
86-R-728	Water line replacement, ANL......................	1,000	0	- 1,000
86-R-729	Upgrade steam distribution system, ORNL.............	2,000	0	- 2,000
86-R-731	Renovation of Applied Sciences Center, Ames....	1,200	0	- 1,200
86-R-732	Addition to Central Research & Administration Bldg, LBL	550	0	- 550
86-R-734	Addition to Applied Math Building, BNL............	1,000	0	- 1,000
86-R-736	Electrical system rehabilitation and improvement, LBL..........	1,700	0	- 1,700
86-R-738	Electrical system rehabilitation, ANL.......	1,200	0	- 1,200
86-R-739	Multiprogram technical support facility, RL......	400	0	- 400
86-R-744	Mechanical system rehabilitation, ANL......	750	0	- 750
	Subtotal...............	$50,700	$29,300	$-21,400
Environmental Compliance				
Operating Expenses...............		$13,300	$12,900	$- 400
Capital Equipment................		1,000	1,000	0
Construction.....................		8,000	8,000	0
Subtotal.......................		22,300	21,900	- 400
Total MLFS..................		$73,000	$51,200	$-21,800

46. Given the information in questions 44 and 45 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for Multiprogram Laboratories Facilities Support?

Answer: The following table reflects the projects that were changed from the IRB Request to the Congressional Submission.

Multiprogram Laboratories Facilities Support
($ in Thousands)

Project #	Title	FY 1986 IRB Request	FY 1986 Cong Request	Change
Multipurpose General Purpose Facilities				
Construction				
	On-going projects..........	$39,150	$28,800	$-10,350
86-R-725	Environment monitoring system upgrade, ORNL.......	1,350	0	- 1,350
86-R-726	Fire Protection Improvements, BNL.................	500	500	0
86-R-727	Upgrade fire protection, ORNL......................	1,400	0	- 1,400
86-R-728	Water line replacement, ANL.......................	1,000	0	- 1,000
86-R-729	Upgrade steam distribution system, ORNL...............	1,100	0	- 1,100
86-R-730	Safety improvements to Pajarito Road, LANL........	500	0	- 500
86-R-731	Renovation of Applied Sciences Center, Ames......	1,200	0	- 1,200
86-R-732	Addition to Central Research & Administration Bldg, LBL.	1,800	0	- 1,800
86-R-734	Addition to Applied Math Building, BNL..............	1,000	0	- 1,000
86-R-735	Engineering and Technical support facility, LBL......	1,000	0	- 1,000
86-R-736	Electrical system rehabilitation and improvement, LBL............	1,300	0	- 1,300
86-R-737	Utility restoration - piping system, ORNL.........	1,000	0	- 1,000
86-R-738	Electrical system rehabilitation, ANL.........	1,200	0	- 1,200
86-R-739	Multiprogram technical support facility, RL.......	400	0	- 400
86-R-740	Science and Technology building, LLNL..............	3,100	0	- 3,100
86-R-741	Electrical and telecommunication system upgrade, INEL.............	1,900	0	- 1,900
86-R-742	Transportation complex, INEL......................	2,000	0	- 2,000
86-R-743	Site entrances improvements, LLNL........	800	0	- 800
	Subtotal................	61,700	29,300	-32,400
Environmental Compliance				
	Operating Expenses................	0	12,900	+12,900
	Capital Equipment.................	0	1,000	+ 1,000
	Construction......................	0	8,000	+ 8,000
	Subtotal.........................	0	21,900	+21,900
	Total MLFS..................	$61,700	$51,200	$-10,500

GENERAL CONSTRUCTION

47. The Committee notes that the actual inflation rate today is significantly less than the estimated projected inflation rate used when many current construction projects were first authorized. It is therefore presumed that some percentage of the estimated costs of a typical project, perhaps as much as 8%, may be retained in various project accounts. The Committee's primary concern is that these funds not be used for projects other than those for which the funds were appropriated and, equally significant, that the original scope of such projects not be expanded to accommodate new features and scope that had not been contemplated when the projects were initiated.

a. How is DOE safeguarding these funds?

Answer: The Department carefully monitors all projects to insure that funds are used for the project for which they are appropriated and also that project scope changes are approved by Congress. The Department has a tradition of dealing with the Committees which has been in place for many years to assure that all funds are fully safeguarded.

It is very premature at this time to draw conclusions that any DOE projects have excess funds as a result of lower nationwide escalation forecasts. Construction escalation is very much dependent on local conditions and the overall bid climate when phases of a project are awarded. Should any excess arise, above that necessary to complete the project, it would be identified to Congress in order that a mutual agreement could be reached on the best use of those funds.

b. How does the Controller verify that contract "changes in scope" are consistently within the boundary limits of the original project description?

Answer: The Office of Project Facilities Management (OPFM) and the Office of the Controller (CR) work very closely with the Office of Energy Research (ER) to insure that changes in project scope are immediately brought to the attention of the appropriate Congressional Committees. ER is the principal office responsible for the management of projects within its budget, however, both CR and OPFM frequently attend project reviews and independently monitor project scope and funding.

For each project supported by ER a planning and management system must be instituted prior to receiving funds. ER requires for each new project included in the budget a conceptual design report and a project management plan that defines the scope, cost, schedule baseline, and management procedures. In order to assure that scope, cost, and schedule changes are identified to senior Department management and to the Congress promptly, ER conducts semi-annual technical, cost, schedule and management reviews and field offices conduct monthly status reviews.

c. **How often are construction projects audited and who conducts such audits?**

Answer: Construction projects are reviewed by the Office of Energy Research, the Office of Project Facilities Management, and by the responsible field office organization. Reviews are made on a monthly basis by the field office and on either a semi-annual or annual basis by Energy Research and by the Office of Project Facilities Management.

d. **How are funds administered for General Plant Projects and Accelerator Improvements? Who in DOE determines how such funds are spent? Who audits these projects? How often are they audited?**

Answer: General Plant Projects (GPP) and Accelerator Improvement Projects (AIP) are administered by the program office in which the funds are budgeted. In the case of the GPP and AIP projects in the Basic Energy Sciences budget, these projects are administered by the Office of Basic Energy Sciences.

The level of funding for GPP and AIP is initially determined within Energy Research (ER) based on overall ER funding targets and a review of needs of the laboratories who have requested funding. These levels are also independently reviewed by the Assistant Secretary for Management and Administration with an objective of assuring that critical laboratory needs are being met.

GPP and AIP are reviewed by the technical staff within Energy Research, by the Office of Project Facilities Management, and by the field offices responsible for the laboratory or site. The field office, due to their proximity and day to day involvement at a site, is the principal reviewing organization and these reviews are ongoing. The reviews conducted by ER are typically combined with technical project reviews at a given site and at a minimum these reviews occur at least once a year.

QUESTIONS CONCERNING THE DEPARTMENT OF ENERGY'S FY 1986 HIGH ENERGY PHYSICS BUDGET REQUEST

GENERAL

1. For FY 1985 and FY 1986, please identify, by accelerator facility, that portion of the High Energy Physics funding going for the support of facilities such as the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory.

Answer: The following table provides the requested information:

(Budget Authority in Thousands)

	Estimated FY 1985	Estimated FY 1986
AGS		
Operating		
Research	7100	7300
Operations	36265	37400
Technology	6300	6600
Equipment	4400	4300
Construction		
AIP	2000	2200
GPP	1350	1100
Fermilab*		
Operating		
Research	9600	9800
Operations	83520	90700
Technology	19600	19200
Equipment	28000	29000
Construction		
AIP	5300	5500
GPP	3000	3000
TeV I	21300	8600
TeV II	12000	0
Central Comp. Upgrade	0	3100

(Budget Authority In Thousands)

	Estimated FY 1985	Estimated FY 1986
SLAC**		
Operating		
Research	11100	11300
Operations	50850	54700
Technology	13100	12600
Equipment	9150	11300
Construction		
AIP	2700	2800
GPP	1500	1700
SLC	60500	22900

* Includes costs associated with fixed target program, preoperations for collider physics, and R&D related to Fermilab facilities.

** Includes costs associated with the fixed target, SPEAR and PEP programs, preoperations for the SLC program, and R&D related to SLAC facilities.

2. **Please provide, by accelerator facility, utilization figures for FY 1985 and FY 1986. What is the optimal level of utilization for each accelerator facility, and what funding level would be required at each facility in FY 1986 to achieve this optimal level of utilization?**

Answer: The table on the following page provides the requested information. The column labeled optimal program defines the optimal utilization which could be achieved in a year in which there were no interference with operations from construction activities. In FY 1986, the optimal utilization at Fermilab and SLAC is strongly limited by the final construction activities on the Tevatron I and SLC projects.

The incremental funding which would be required for the optimal utilization at Fermilab in a normal operating year includes: $14.7 million for operation of the full complement of new beams and experiments during fixed-target operations and for operation of the antiproton source and detectors during colliding beam operations; $2.5 million to support the higher level of activities in the existing fixed target research areas; $7.4 million for the additional power and cryogenic fluids required; and $1.5 million to support the higher physics research effort.

Optimal utilization at SLAC in FY 1986 would be 30 weeks of linac, PEP, and SPEAR operations, at an average pulse rate of 22 percent. The limit of 30 weeks is set by the final SLC construction and installation activities. The incremental funding of $8.0 million which would be required for the optimal utilization at SLAC in FY 1986 includes: $1.1 million for accelerator operations, $2.2 million for accelerator maintenance, $1.4 million for replacement klystrons and thyratrons in the linac, $1.8 million for the additional electrical power used, and $1.5 million for experimental facilities support. In a normal operating year, with optimal utilization of the linac fixed target facility, PEP, SPEAR, and the SLC, there would be 44 weeks of beam operations at an average pulse rate of 38 percent, and a further incremental cost of $37.0 million in addition to the $8.0 million discussed above.

In addition, laboratory and university physics research groups would require about $25.0 million more to fully exploit the beam time provided by optimal utilization of all of the accelerator and colliding beam facilities.

Weeks Operations for Physics Research

	Expected FY 1985	Planned FY 1986	Optimal Program[1]	Additional Funding for Optimal Program	Additional Funding for Optimal Program in FY 1986
Brookhaven National Laboratory					
● Slow Extracted Beam	17	12	20		
● Fast Extracted Beam	13	9	10		
● Polarized Beam	0[2]	9	10		
Total	30	30[3]	40[3]	$8.0M	$8.0M
Fermi National Accelerator Laboratory					
● Fixed Target	30	19	28		
● Colliding Beams	0	4	20		
Total	30	23[4]	48	$24.6M	$3.0M[5]
SLAC					
● Linac, PEP, SPEAR	27	22	44	$45.0M	$8.0M[6]
● Average Pulse Rate	18%	14%	38%		
Associate Research Costs				$25.0M	$7.0M

[1] This program assumes SLC and Tevatron I are in operation.

[2] There will also be 3 to 4 weeks of operation for commissioning the Polarized Proton Beam.

[3] In addition, there will be 2 to 3 weeks of commissioning the Heavy Ion Beam (funded by Nuclear Physics).

[4] In addition, there will be extensive Antiproton Source tests using the Linac, Booster, Debuncher, and Accumulator during much of the remainder of the year.

[5] During FY 1986, the construction work required to complete Tevatron I will limit the weeks of running to the planned FY 1986 level. However, the reliability of accelerator operations and research productivity of the Fermilab program and thus utilization could be improved with the additional funding indicated.

[6] During FY 1986 only, the construction work and installation required to complete SLC will limit the optimal weeks of running the Linac, PEP, and SPEAR for high energy physics to 30 weeks at an average pulse rate of 22 percent.

3. **For FY 1985 and FY 1986, please provide, by DOE laboratory, the amount of High Energy Physics funding going to DOE laboratories.**

Answer: The following table provides the estimated funding levels for DOE laboratories.

High Energy Physics
DOE Laboratory Funding
(In Thousands)

	Estimated FY 1985	Estimated FY 1986
Ames Laboratory		
Operating........................	$ 810	$ 810
Equipment........................	450	500
Argonne National Laboratory		
Operating........................	6,100	6,300
Equipment........................	500	500
Brookhaven National Laboratory		
Operating........................	63,665	65,500
Equipment........................	7,900	8,200
Construction.....................	7,700	7,900
Fermi National Accelerator Laboratory		
Operating........................	118,720	126,500
Equipment........................	28,000	29,000
Construction.....................	41,600	20,200
Lawrence Berkeley Laboratory		
Operating........................	16,800	17,400
Equipment........................	1,300	1,500
Los Alamos National Laboratory		
Operating........................	445	440
Oak Ridge National Laboratory		
Operating........................	450	450
Pacific Northwest Laboratory		
Operating........................	100	90
Stanford Linear Accelerator Center		
Operating........................	77,350	81,600
Equipment........................	9,500	11,300
Construction.....................	64,700	27,400

4. **For FY 1985 and FY 1986, please provide the amount of High Energy Physics funding going to university researchers.**

Answer: In FY 1985, the estimate is $79.5 million and in FY 1986, $81.9 million.

5. **For FY 1985 and FY 1986, please provide, by entity, the amount of High Energy Physics funding going to non-DOE laboratory, non-university entities, including industrial firms.**

Answer: The bulk of the high energy physics funding going to non-DOE laboratory, non-university entities is handled via subcontracts directly between these institutions and the national laboratories and, to a much lesser extent, with universities. Those entities falling into the described category and funded directly by DOE, exclusive of Small Business Innovative Research (SBIR) contracts, are listed below.

	(Dollars in Thousands)	
	Estimated FY 1985	Estimated FY 1986
Entity		
Franklin Institute	145	160
Harry Diamond Laboratory	20	20
Houston Area Research Center, Central Design Group & Other SSC	9,900	10,800
Institute for Advanced Study	485	485
LaJolla Institute	100	100
National Bureau of Standards (Gaithersburg)	135	110
National Bureau of Standards (Boulder)	210	230
Naval Research Laboratory	195	195
Spectra Technologies, Inc.	340	250
Supercon, Inc.	0	250

6. **For FY 1985 and FY 1986, please provide, by agency, the amount of High Energy Physics funding going to other agencies, such as the National Science Foundation.**

Answer: The following table provides the requested information:

	(Dollars in Thousands)	
	Estimated FY 1985	Estimated FY 1986
Harry Diamond Laboratories	$ 20	$ 20
National Bureau of Standards (Gaithersburg)	135	110
National Bureau of Standards (Boulder)	210	230
Naval Research Laboratory	195	195

7. **For FY 1985 and FY 1986, please provide, by agency, the amount of High Energy Physics funding received from other agencies, such as the National Science Foundation.**

Answer: No funding is expected to be received from other agencies for high energy physics research in FY 1985 or FY 1986.

8. **For FY 1985 and FY 1986, please provide, by foreign institution or nation, actual and estimated High Energy Physics program funding going to support high energy physics research at foreign institutions.**

Answer: No DOE funding is provided for high energy physics research to foreign institutions. DOE does provide funds for scientists from U.S. institutions to perform experiments using high energy physics facilities having unique capabilities at the foreign institutions. Estimated funding levels are indicated below and include salaries, travel, and equipment for the U.S. groups.

(Dollars in Millions)

	Estimated FY 1985	Estimated FY 1986
DESY/West Germany	$ 2.0	$ 1.8
CERN/Switzerland	10.2	11.5
KEK/Japan	2.0	2.1
	$14.2	$15.4

The number of U.S. scientists involved in such experiments is about:

	Estimated FY 1985	Estimated FY 1986
DESY/West Germany	50	40
CERN/Switzerland	85	100
KEK/Japan	20	20
	155	160

9. **For FY 1985 and FY 1986, please provide, by foreign institution or nation, actual and estimated High Energy Physics program funding received from other nations for support of high energy physics research in the U.S.**

Answer: There is direct funding received by the U.S. from Japan for US/Japan high energy physics collaborative programs carried out at U.S. laboratories in cooperation with Japanese personnel. This funding is estimated to be constant over FY 1985 and FY 1986; however, it is subject to variation in large part due to the yen/dollar relationship:

(Dollars in Millions)

	Estimated FY 1985	Estimated FY 1986
Japan	$5.5	$5.5

This funding is for direct research and equipment costs in addition to the salary and other support costs provided separately to the Japanese scientists by their government. The annual number of visiting scientists (for periods of days to months) to U.S. laboratories associated with these research, accelerator, and detector R&D programs is:

	Estimated FY 1985	Estimated FY 1986
Number of Japanese Scientists during year	100	100

Other than Japan, no direct funding is received from any other nation for collaborative research and R&D programs, although salary and other support costs are provided for these foreign scientists by the home government, as in the case of Japan.

In addition, foreign scientists frequently provide equipment to incorporate in experiments at U.S. laboratories. The estimated value of equipment provided by foreign scientists over FY 1985 and FY 1986 is:

(Dollars in Millions)

	Estimated FY 1985	Estimated FY 1986
BNL	$0.3	$0.3
FNAL	6.65	4.50
SLAC	0.205	0.70

The collaborative programs, involving participation of foreign scientists, are quite extensive, involving many institutions and nations having major research and R&D programs in the U.S. The following table provides estimates of the number of European and other non-Japanese scientists making working visits to DOE accelerator laboratories in the past year:

	BNL	FNAL	SLAC
No. of Foreign Scientists	100	180	150
No. of Foreign Institutions	20	30	25

The duration of these visits can be anything from about a week to about a year. The average stay is estimated to be about 3-4 months. Many of these visiting scientists work in collaboration with U.S. universities and are also visitors to these institutions.

In addition, there are other visiting scientists to universities. No good statistics are available on these visits.

10. How many Ph.D. level researchers are being supported by the program in FY 1985, and how many are expected to be supported in FY 1986?

Answer: The high energy physics program is supporting an estimated 1525 Ph.D. level researchers in FY 1985. In FY 1986, this is projected to decrease to somewhat below 1500.

11. **How much did the High Energy Physics Program contribute to the support of DOE's Small Business Innovative Research (SBIR) Program for FY 1984? How much is estimated for FY 1985 and FY 1986?**

Answer: The high energy physics program contributed $2,053,000 in FY 1984 for the Small Business Innovation Research Program. The estimates for the SBIR Program in FY 1985 and 1986 are $3,720,000 and $3,911,000, respectively.

12. **The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the High Energy Physics program totalled $642.2 million, including $477.6 million for operating expenses and $164.6 million for plant and capital equipment. According to these Tables, the Department's FY 1986 submission to OMB totalled $599.7 million, including $453.0 million for operating expenses and $146.7 million for plant and capital equipment. What are the specific differences between these two budgets?**

Answer: The Following table indicates the changes from the Internal Review Budget request to the OMB request.

(Budget Authority in Thousands)

	FY 1986 IRB Request	FY 1986 OMB Request	Change
Physics Research			
Operating Expenses	$ 116,900	$ 117,900	+ $ 1,000
Facility Operations			
Operating Expenses	208,700	204,700	- 4,000
Capital Equipment	81,700	79,600	- 2,100
Construction	82,900	67,100	- 15,800
Subtotal	373,000	351,400	- 21,900
High Energy Technology			
Operating Expenses	152,000	130,400	- 21,600
Total	$ 642,200	$ 599,700	- $ 42,500

The changes in Operating Expenses for Physics Research (+1,000,000) and Facility Operations (-$4,000,000) reduce average facility utilization from the 55-60 percent range to about 55 percent. Physics Research has been matched to the planned facility utilization level.

The change in Capital Equipment (-$2,100,000) causes some slowdown in progress on major new detectors for Tevatron and SLC.

The change in construction (-$15,600,000) substantially reduces the funding for initiation of the AGS Accumulator/Booster and the Fermi Central Computing Upgrade.

The change in High Energy Technology (-$21,600,000) reduces the level of R&D related to the Superconducting Super Collider somewhat and substantially reduces other R&D not related to SSC.

13. As noted in question 12 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $599.7 million, including $453.0 million for operating expenses and $146.7 million for plant and capital equipment, and the FY 1986 Congressional request for Nuclear Physics totalled $510.1 million, including $391.5 million for operating expenses and $118.6 million for plant and capital equipment. (a) What was the original OMB passback? (b) What specific items much did the Department appeal to have included in the Congressional request that are not included in the Congressional request? (c) What are the specific differences between these two budgets?

Answer: Development of the FY 1986 budget was not a traditional or formal process and involved many discussions and informal interim steps. Specific differences between the High Energy Physics OMB and High Energy Physics Congressional budget requests are given below:

(Budget Authority in Thousands)

	FY 1986 OMB Request	FY 1986 Cong. Request	Change
Physics Research			
Operating Expenses	$ 117,900	$ 111,300	- $ 6,600
Facility Operations			
Operating Expenses	204,700	187,800	- 16,900
Capital Equipment	79,600	63,100	- 16,500
Construction	67,100	55,500	- 11,600
Subtotal	351,400	306,400	- 45,000
High Energy Technology			
Operating Expenses	130,400	92,400	- 38,000
Total	$ 599,700	$ 510,100	- $ 89,600

The changes in Operating Expenses for Physics Research (-$6,600,000) and Facility Operations (-$16,900,000) reduce average facility utilization from the 55 percent range to below 50 percent after priority consideration is given for pre-operation tests of Tevatron I and SLC. Physics Research has been matched to the planned lower facility utilization level.

The change in Capital Equipment (-$16,500,000) reduces the ability to provide major new detectors for the Tevatron (D-Zero) and SLC. Funding for these new detector needs is reduced from $43,800,000 to $30,600,000.

The change in construction (-$11,600,000) precludes initiation of the AGS Accumulator/Booster, substantially reduces first year funding for the new Fermi Central Computing Upgrade, provides somewhat reduced funding for AIP and GPP projects, and allows for modest funding increases for completion of Tevatron I and SLC.

The change in High Energy Technology (-$38,000,000) was allocated to reducing the funding requested for SSC R&D to maintain the FY 1985 level of $20,000,000.

14. Given the information in questions 12 and 13 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for Nuclear Physics?

Answer: The following table indicates the changes from the Internal Review request to the Congressional request.

(Budget Authority in Thousands)

	FY 1986 IRB Request	FY 1986 Cong. Request	Change
Physics Research Operating Expenses	$ 116,900	$ 111,300	- $ 5,600
Facility Operations			
Operating Expenses	208,700	187,800	- 20,900
Capital Equipment	81,700	63,100	- 18,600
Construction	82,900	55,500	- 27,400
Subtotal	373,300	306,400	- 66,900
High Energy Technology Operating Expenses	$ 152,000	92,400	- 59,600
Total	$ 642,200	$ 510,100	- $132,100

The reduction in Operating Expenses for Facility Operations (-$20,900,000) and Physics Research (-$5,600,000) reduces the average facility utilization level from 60 percent range to a level below 50 percent, after priority consideration is given for pre-operating tests of Tevatron I and SLC. Physics Research has been matched to the planned lower facility utilization level.

The change in Capital Equipment (-$18,600,000) reduces the ability to provide the new detectors for the Tevatron and SLC. Funding for these new detector needs is reduced from $45,900,000 to $30,600,000.

The reduction in High Energy Technology (-$59,600,000) will maintain the level of R&D related to the SSC at the FY 1985 level ($20,000,000) and reduces the funding planned for other advanced technology R&D efforts.

SUPERCONDUCTING SUPER COLLIDER (SSC)

15. What is the estimated distribution of funding, by performer, for the Superconducing Super Collider (SSC) R&D for FY 1985 and FY 1986?

Answer: The following table gives the estimated distribution of funding for SSC R&D for FY 1985 and FY 1986. The FY 1985 distribution reflects the latest input from the SSC Central Design Group (CDG), and most of these funds are already allocated to the specific performers.

The FY 1986 distribution as indicated in the budget request to the Congress is a very preliminary estimate. The actual FY 1986 program will be strongly influenced by which magnet type is selected and by CDG plans for optimized progress within the $20 million funding level requested for FY 1986.

(Dollars in Millions)

	Estimated FY 1985	Estimated FY 1986
BNL	$ 5.3	$ 5.0
Fermilab	4.0	2.8
LBL	0.8	1.4
Texas Accel. Ctr.	5.0	
Central Design Group	4.9	10.8
Other	---	
	$20.0	$20.0

16. Please list the SSC ongoing and planned tasks for FY 1985 and FY 1986, as well as the planned funding levels for each.

Answer: The SSC tasks ongoing for FY 1985 are as follows:

1) magnet R&D and other studies to provide the technical basis for selection of the magnet type late in FY 1985, including

   a) fabrication and testing of prototypes of a variety of magnet types,

   b) establishment of a technical magnet review panel to delineate an FY 1985 magnet R&D program which will provide the minimum set of technical data required for the magnet type selection process,

   c) establishment of an aperture task force to define required dynamic aperture,

   d) establishment of a task force to analyze magnet costs, and

   e) establishment of a task force to consider the impact of various magnet design features on commissioning and operation of the SSC;

2) development of technical site criteria, to include submission of a site criteria report to DOE by April 15, 1985;

3) preliminary systems design activities; and

4) R&D on other technical systems such as cryogenics, vacuum, etc. and on development of improved superconductor cable.

The SSC tasks presently planned for FY 1986 are as follows:

1) development of cost/performance optimized design of the selected magnet type;

2) development of cost effective fabrication techniques for superconducting magnets;

3) preparations, including fabrication of some prototype magnets, for system tests with the final magnet type in FY 1987;

4) providing the technical and cost information required for the Department to decide on whether and how to proceed with the SSC, including optimized SSC system designs and cost estimates; and

5) R&D on other technical systems such as cryogenics, vacuum, injector, controls, etc., and on development of improved superconductor cable.

CONSTRUCTION

General Plant Projects (Project No. 86-R-103)

17. **Please provide a brief description of each of the proposed GPP projects at BNL for FY 1986. Please provide a detailed explanation of the GPP project titled "Construction of Applied Science Whole-Building Test Facility." What is it? What will it do? Who will sponsor the research at this facility?**

Answer: The following provides a brief description of the GPP projects at BNL.

Improvements to North Area Building................................$200,000

A former bubble chamber building requires improvements to house technical shops for the survey, repair, and alignment of radioactive neutrino horns and beam separators. A small lean-to addition will also be constructed for the storage of spare parts, tools, and associated equipment.

Additional Building for Neutrino Power Supply and Screen Room......$150,000

A new building of approximately 1,500 square feet is required for the neutrino power supply at its new location. Services including heat, lighting, power, and adequate air conditioning for the power supply equipment will be provided. A screen room is included to shield and isolate low voltage controls and monitoring devices.

Improvements to Water System.......................................$900,000

The project provides for the installation of approximately 6,500 linear feet of replacement water mains to eliminate undersized and unlined 6" and 8" old cast iron pipes in the southern sector of the site. New 10" and 12" PVC and cement lined cast iron water mains will be installed to improve water pressure, quality, and quantity. The Laboratory's fire fighting capabilities will also be enhanced as a result of this installation.

Construction of Radiation Storage Building........................$300,000

A new building is required to store all the high radiation equipment and experimental devices for the Alternating Gradient Synchrotron (AGS) in one centralized and controlled area. Approximately 5,000 square feet of building space, designed for heavy floor loading and having large access doors, will be provided. Also included, is a fenced-in, paved storage compound adjacent to the new building.

Modification of Office Builidng and Upgrade of Air Conditioning System..$150,000

In order to provide for more efficient use of existing space and conservation of energy, the south wing of an office building will be modified and new heating, ventilation, and air conditioning equipment will be installed. Several toilet rooms in an adjacent area will also be improved.

Improvements to Assembly and Staging Building......................$450,000

In order to facilitate development work in the high energy research program, several improvements and an addition to the Assembly and Staging Building are required. The existing building will be air conditioned and a 15-ton overhead crane is required. A small 1,200 square foot addition for toilets and a lunch room will be constructed and the main electrical service will be increased from 400 amps to 600 amps.

Construction of Roads and Hardstands...............................$700,000

This road project provides for the construction of a new two-lane, heavy duty roadway with drainage and safety shoulders. The trafficway is required because Railroad Street will be eliminated upon consolidation of the National Synchrotron Light Source (NSLS) site. For ease of operation and all-weather access to the collider central complex, permanent asphalt paved hardstands and access roads are required around the main building and compressor structures.

Modifications to Medical Building..................................$300,000

The number of programs utilizing tissue culture for research has grown significantly. The number and magnitude of use is expected to increase in the near future. Existing laboratory space in the Medical Building will be modified to create a sterile environment and serve as a Tissue Culture Facility. Fume hoods containing air filtered systems, incubators, and other associated equipment will be furnished and installed.

Machine Shop Addition..$300,000

A materials receiving area contiguous to the heavy machine shop is required. A 2,000 square foot addition, complete with heat, lighting, overhead doors, and loading/unloading dock sized for fork lift operations will be constructed. All items designated for shop fabrication or assembly will be directed to the new area for acceptance and processing. Valuable shop space now used for this purpose will be available for other use.

Steam Distribution System Extension..............................$900,000

The existing underground central steam distribution system will be extended down the southeast area of the site to the boiler house serving several warehouses and shops. This extension will enable the removal of an old inefficient No. 4 oil fired steam boiler which has outlived its useful life.

Energy Measurement System......................................$850,000

An energy monitoring system with necessary source electric and steam meters and transmitters will be installed. This system will identify specific buildings and facilities using excessive amounts of energy. Based on data received and engineering analyses, management decisions can be made to make the required corrective measures to reduce energy usage.

Construction of Applied Science Whole-Building Test Facility.......$500,000

The General Plant Project (GPP) for construction of an Applied Science Whole-Building Test Facility will provide a building shell 40 feet in height and containing approximately 5,000 square feet. This facility will be utilized for research sponsored primarily by the Buildings and Community Systems programs under the cognizance of the Assistant Secretary for Conservation and Renewable Energy. The facility will have the capability of replicating controlled atmospheric and environmental conditions and will be used to research the efficiency of integrating various building subsystems, developed for various DOE projects, with the aim of establishing a coherent building installation application.

General Plant Projects provide for minor conventional construction including buildings, building additions, and other improvements including improvements to land and utility systems whose total estimated costs do not exceed $1 million per project. The Department has assigned landlord responsibility for all General Plant Projects at the Brookhaven National Laboratory, a DOE multi-program facility, to the High Energy Physics program. For this reason many of the projects listed above support research sponsored by numerous DOE programs.

Tevatron I (Project No. 81-E-218)

18. **The October 1984 Construction Project Sheet contained in the FY 1986 Congressional Budget Request indicates that the Tevatron I's conventional construction costs for experimental areas increased by $1.5 million (from $10.1 million to $11.6 million) from the October 1983 estimate. What were the reasons for this increase?**

Answer: The research detector to be assembled in the second Tevatron I experimental area, and the area itself, were both in conceptual design in October 1983. As the design for the D-Zero detector matured, the requirement for the experimental area grew in terms of increased area and support facilities. Therefore, the current estimated cost of these facilities is $1.5 million higher than the earlier estimate.

19. **The October 1984 Construction Project Sheet contained in the FY 1986 Congressional Budget Request indicates that the Tevatron I's other project costs increased by $4.2 million (from $46.3 million to $50.5 million) from the October 1983 estimate. What were the reasons for this increase?**

Answer: The $4.2 million increase in the Tevatron I's other project costs arose primarily from increased costs of the Accumulator Ring, which is being fabricated as part of the R&D effort because this was a challenging system with significant technical uncertainties. There were technical problems with achieving adequate magnet field quality and delays in procuring magnet laminations. These problems resulted in higher costs due to the need for additional magnet-construction fixtures and for more labor in the magnet factory. Increased costs were also incurred for other Accumulator Ring systems, including beam diagnostics, vacuum and stochastic cooling.

20. **What escalation rates were used in the October 1983 cost estimate for this project? What escalation rates were used in the October 1984 cost estimate for this project? What would the October 1984 cost estimate have been if the October 1983 escalation rates were used?**

Answer: The October 1983 cost estimate of $82,500,000 for the Tevatron I project was developed in FY 1984 dollars with escalation rates for fiscal years 1985 and 1986 projected at 6.4 percent and 7.7 percent, respectively. The October 1984 cost estimate of $84,000,000 was developed in FY 1985 dollars with an escalation rate of 6.4 percent applied to the FY 1986 costs. If the October 1983 cost estimate escalation rates were used in developing the October 1984 cost estimate, the cost estimate would have increased by approximately $200,000 to $84,200,000.

Tevatron II (Project No. 82-E-206)

21. **Please provide a status report of this project.**

Answer: The Tevatron II construction project is nearing completion. The current cost estimate is identical to the original cost estimate of $49.0 million. Of this amount, 83 percent has been committed and 75 percent costed. The upgrade of the extraction system and the external beam switchyard to a 1 TeV capability was completed in 1983. Now that 1 TeV targeting capability has been provided in existing experimental areas, 13 experiments and 2 test beams are available for operation at full beam energy. The new experimental halls for the muon beam and the wide band photon beam have been completed, and the corresponding beam line enclosures are nearly completed. The experimental halls and beam line enclosures at the meson west beam and the polarized proton beam were delayed during the design stage, and civil construction is just beginning. These last two elements are now scheduled for completion in mid-1986. At the end of FY 1985, we anticipate that the Tevatron II construction project will be fully committed and 94 percent costed.

SLAC Linear Collider (Project 84-ER-133)

22. **The November 1984 Construction Project Sheet contained in the FY 1986 Congressional Budget Request indicates that the SLC's total construction cost has increased by $3.4 million, from $112.0 million to $115.4 million "to reflect the impact of reduced first year funding and increased klystron costs". (a) Please provide a detailed explanation of each of the components of this cost increase. (b) How much of the project's contingency remains? (c) Does the increased cost include the 180 Hertz capability for the SLC and if not, how much additional cost will be required to achieve this capability?**

Answer: (a) The total SLC cost increase of $3.4 million shown in the November 1984 Construction Project Data Sheet has two components. Approximately $800,000 of the total is estimated to be due to inflation on the $8 million Congress appropriated in FY 1985 instead of in FY 1984 as the DOE requested. The balance of approximately $2,600,000 is due to increased costs of the 50 MW klystron tubes and of the thyratrons. Production of the new klystron tubes was delayed from January 1984 to February 1985 because of technical problems with the high current cathodes, ceramic windows used to isolate tube vacuum from accelerator vacuum, and frequency instability measured in prototypes. The switch tubes (thyratrons) used in the klystron modulators did not last in full power operations and new switch tubes are being procured from industry. The increase in cost of the klystrons and the modulators is based on an estimate developed by SLAC for the November 7-8, 1984, DOE semiannual technical, cost, and schedule review. As of March 1, 1985, 16 of the new 50 MW tubes have been placed in the linac. Additional tubes will be installed as they become available.

(b) The amount of contingency, $14.5 million, shown in the November 1984 Construction Project Data Sheet, is based on the November 7-8 DOE semiannual technical, cost, and schedule review. It represents the best estimate of contingency available at that time. The next semiannual review, scheduled for May 1985, will update this. The major known lien against contingency at this time is the cost of new thyratron switch tubes, which has a worst case estimate of about $2 million. This number may be reduced through a combination of modifications to the klystron modulator circuits and careful work with industrial sources. The remaining contingency is believed adequate to complete the project within the revised total estimated cost.

(c) The $115.4 million total estimated cost does not include 180 Hertz capability for SLC. While the SLC itself will have the full potential for 180 Hertz operation, power substation equipment located along the linac must be upgraded to handle the higher average power requirement for operating 50 MW klystrons at 180 Hertz. The estimated cost of this equipment is approximately $5.5 million.

23. **The November 1984 Construction Project Sheet contained in the FY 1986 Congressional Budget Request indicates that the SLC's other project costs decreased from the October 1983 estimate by about $2.3 million, from about $23.7 million to nearly $21.4 million. What savings were made that resulted in this decrease?**

Answer: The change in "other project costs" (section 12.A.2) between the November 1984 Stanford Linear Collider (SLC) Construction Project Data Sheet (FY 1986 Congressional Budget Request) and the similar one for 1983 reflects a complex set of readjustments and changing needs and estimates with respect to the SLC project at the Stanford Linear Accelerator Center (SLAC). The change is due predominantly to a reduction in the "R&D Necessary to Complete Construction" [section 12.A.2.(a)] estimated for FY 1985 and FY 1986 of approximately $2.4 million. Other adjustments in this section tend to offset each other over the three-year period (FY 1984 to FY 1986) shown in the data sheets. The changes in estimated R&D reflect primarily: a shift in klystron development to multiple prototypes which must be costed under construction instead of R&D (a reflection of the nature of the klystron development problem) and exceptionally good progress in other areas of R&D in support of the SLC, driven in part by the very tight construction schedule.

24. **The November 1984 Construction Project Sheet contained in the FY 1986 Congressional Budget Request indicates that the SLC's total related incremental annual costs in FY 1986 dollars has increased from the October 1983 estimate by $1.3 million, from $15.7 million to $17.0 million, but that the "programmatic operating costs directly related to the facility" decreased from $5.2 million to $2.5 million. What accounts for this decrease?**

Answer: The estimates for SLC "Other Related Annual Costs" shown in Section 12.B of the November 1984 Construction Project Data Sheet show two major changes from the October 1983 estimate. First the facility operating costs (12.B.1) have increased from $9,600,000 to $13,600,000. This is primarily due to the substantial increase in electric power rates anticipated by FY 1987. The reduction in programmatic operating cost (12.B.2) from $5,200,000 in the October 1983 estimate to $2,500,000 in the November 1984 Construction Project Data Sheet reflects a reconsideration and more careful estimate of the costs to SLAC of carrying out the programmatic high energy physics research by in-house physicists and physicists from the user community.

25. **What escalation rates were used in the October 1983 cost estimate for this project? What escalation rates were used in the November 1984 cost estimate for this project? What would the November 1984 cost estimate have been if the October 1983 escalation rates were used?**

Answer: The escalation rates used in the October 1983 estimate were 8 percent, 9 percent, and 9 percent, for the Fiscal Years 1984, 1985 and 1986, respectively. In the November 1984 estimate 8 percent and 7 percent were used for Fiscal Years 1985 and 1986. The FY 1984 figures are based on actual expenses as determined at the November 7-8, 1984, DOE semiannual technical, cost, and schedule review of the SLC project. The November 1984 cost estimate would be increased by about $2,800,000 if the October 1983 escalation factors were used for the two out-years and the actual FY 1984 costs are assumed for the first year of construction.

QUESTIONS AND ANSWERS CONCERNING THE DEPARTMENT OF ENERGY'S FY 1986 NUCLEAR PHYSICS BUDGET REQUEST

GENERAL

1. **For FY 1985 and FY 1986, please identify, by accelerator facility, that portion of the Nuclear Physics funding going for the support of facilities, such as the Clinton P. Anderson Meson Facility at Los Alamos (LAMPF).**

Answer:

National Accelerator Facilities
Facility Operations
(B/A in thousands of dollars)

Accelerator Facility	FY 1985	FY 1986
ANL--ATLAS	$ 2,795	$ 2,795
BNL--Tandem/AGS	1,500	3,550
LBL--Bevalac	17,360	17,780
LBL--88-Inch Cyclotron	2,110	2,150
LANL--LAMPF	39,245*	39,765
MIT--Bates	5,675	5,675
ORNL--Holifield	4,955	4,955
SLAC--NP Injector	1,090	1,450
Nuclear Physics Total	$74,730	$78,120

* Includes $3,100,000 Defense Programs support of LAMPF operations.

Each of the above facilities provides beam time for nonproprietary research on the basis of scientific priority and technical feasibility of experimental proposals reviewed by peer review committees called program advisory committees. The "program advisory committee" for a given facility is appointed by and reports to the director of that facility. Typically 40% to 60% of each facility's beam time for research is made available to outside, university-based users.

The above Facility Operations costs include all costs of accelerator operations (including electric power) and maintenance as well as the costs of operating and maintaining permanently installed equipment such as beam lines, beam dumps, and magnetic spectrometers. Not included are costs of setup and execution of individual experiments, support of in-house research, support of outside user research, or Plant and Capital additions to the accelerator laboratory.

To complement these national accelerator facilities, the Nuclear Physics program supports dedicated on-campus accelerators at Yale University, Duke University, University of Washington, and Texas A&M University. In FY 1985 operations costs of the dedicated on-campus facilities are estimated at $3,140,000; $3,140,000 is also budgeted for FY 1986.

2. **Please provide, by accelerator facility, utilization figures for FY 1985 and FY 1986. What would be an optimal level of utilization for each accelerator facility, and what funding level would be required at each facility in FY 1986 to achieve this optimal level of utilization?**

Answer:

National Accelerator Facilities
Beam Hours for Research

Accelerator Facility	FY 1985	FY 1986
ANL--ATLAS	2,500	3,500
BNL--Double MP Tandem	1,920	500
BNL--Tandem/AGS*	0	100
LBL--Bevalac	3,500	3,000
LBL--88-Inch Cyclotron	3,500	3,200
LANL--LAMPF	2,850	3,200
MIT--Bates	2,500	2,400
ORNL--Holifield	4,000	2,100
SLAC--NP Injector**	700	1,000
Total	21,470	19,300

* First operation in FY 1986
** First operation in FY 1985

In FY 1986 full utilization of these national accelerator facilities would be 42,000 beam hours for research. A 60% utilization factor represents a reasonable goal for effective utilization of these facilities. Attainment of a 60% utilization factor in FY 1986 would require $162.7 million in total operating expenses for the Nuclear Physics program in FY 1986. This total includes costs of accelerator facility operations and associated in-house and user research.

3. **For FY 1985 and FY 1986, please provide, by DOE laboratory, the amount of Nuclear Physics funding going to DOE laboratories.**

Answer:

Nuclear Physics Funding to National Laboratories
(B/A in thousands of dollars)

Operating Expenses	FY 1985	FY 1986
Ames	$ 220	$ 220
ANL	10,700	10,700
BNL	7,859	10,260
LBL	29,095	29,555
LLNL	180	100
LANL	48,568	48,645
ORNL	9,961	10,030
SLAC	1,090	1,450
Total Operating Expenses	$107,673	$110,960

Plant and Capital Equipment	FY 1985	FY 1986
Ames	$ 0	$ 0
ANL	2,345	2,185
BNL	8,045*	3,595
LBL	7,525**	7,325**
LLNL	0	0
LANL	4,580	4,180
ORNL	1,140	1,615
SLAC	0	150
Total Plant and Capital	$ 23,635	$ 19,050

* Includes $5,000,000 for the Tandem/AGS Heavy Ion Transfer Line construction project.

** Includes $3,300,000 each year for laboratory-wide General Purpose Equipment and General Plant Projects' requipements

4. **For FY 1985 and FY 1986, please provide the amount of Nuclear Physics funding going to university researchers.**

Answer: In FY 1985, the DOE's Nuclear Physics program plans to provide direct support totaling $36.4 million in Operating Expense funds and $12.4 million in Plant and Capital Equipment funds to university researchers. In FY 1986, it is estimated that $37.8 million in Operating Expense funds and $2.0 million in Plant and Capital Equipment funds will be provided as direct support to university researchers. In FY 1985, the funding for the University Accelerator Upgrade Project at the University of Washington and Yale University will be completed; this construction project accounts for $11.0 million of the $12.4 million in Plant and Capital Equipment funds provided in direct support to university researchers in FY 1985. University support in an amount approximately equal to the direct support is also provided through DOE funding of Nuclear Physics accelerator centers in the form of services in support of experiments by university scientists and delivery of particle beams to these experiments.

5. **For FY 1985 and FY 1986, please provide, by entity, actual and estimated Nuclear Physics funding going to non-DOE laboratory, non-university entities, including industrial firms.**

Answer: The planned funding for FY 1985 and requested funding for FY 1986 to non-DOE laboratory and nonuniversity entities, including industrial firms is given in the following table:

Nuclear Physics Funding to
Non-DOE Laboratories and Non-university Entities
(B/A in thousands of dollars)

	FY 1985	FY 1986
Fermi Awards	$ 200	$ 200
Lawrence Awards	60	60
National Bureau of Standards	937	1,000
Small Business Innovation Research*	1,425	1,509
Washington Consulting Group	57	0
Total	$2,679	$2,769

* Recipients of FY 1985 and FY 1986 Small Business Innovation Research Awards have not yet been selected.

6. **For FY 1985 and FY 1986, please provide, by agency, the amount of Nuclear Physics funding going to other agencies, such as the National Science Foundation and the National Bureau of Standards.**

Answer: The planned FY 1985 funding and requested FY 1986 funding to other agencies such as the National Science Foundation and the National Bureau of Standards are given in the following table:

Nuclear Physics Funding to
Other Agencies
(B/A in thousands of dollars)

	FY 1985	FY 1986
National Bureau of Standards	$ 937	$1,000
Total	$ 937	$1,000

7. **For FY 1985 and FY 1986, please provide, by agency, the amount of Nuclear Physics funding received from other agencies, such as the National Science Foundation or the National Bureau of Standards.**

Answer: No transfers of funds from other agencies to the DOE's Nuclear Physics program are planned in either FY 1985 or FY 1986.

8. **For FY 1985 and FY 1986, please provide, by foreign institution or nation, actual and estimated funding going to support nuclear physics research at foreign institutions.**

Answer: In FY 1985 and FY 1986, the Nuclear Physics program plans no direct funding to any foreign institution. Funding is provided, however, to support scientists from United States universities and DOE laboratories in carrying out experimental or theoretical research at foreign institutions. Estimates of the amounts provided for significant activities of this type are contained in the following table:

Nuclear Physics Funding to Research in Foreign Countries
(B/A in thousands of dollars)

Nation	FY-1985	FY-1986
Switzerland	$ 2,250	$ 2,300
West Germany	600	600
France	400	400
Canada	300	300
Denmark	150	150
England	100	100
Japan	50	50
Netherlands	50	50
Belgium	10	10
China	10	10
	$ 3,920	$ 3,970

9. **For FY 1985 and FY 1986, please provide, by foreign institution or nation, actual and estimated funding or other support received for nuclear physics research in the U.S.**

Answer: No direct payments are received from other nations or foreign institutions for nuclear physics research carried out in the United States. Research groups from other nations are, however, involved very actively in nuclear physics programs using United States' facilities. For example, scientists from West Germany and Japan have established active research programs at the Bevalac and are pursuing plans for involvement in the BNL Tandem/AGS heavy ion nuclear research program. These activities have entailed considerable expenditure of funds by the foreign institutions involved. These costs have included major equipment items as well as the salaries and travel of the foreign participants. However, just as in the case of United States' scientists using foreign facilities, no direct payments are made to the host institution by the user. Lacking specific, detailed information on the costs incurred by foreign institutions for their nuclear physics research activities in the United States, we estimate that the total amount of such expenditures is not dramatically different from our costs for nuclear physics research at foreign institutions. The distribution by country is, however, quite different.

10. **How many Ph.D. level researchers were supported by this program in FY 1984, and how many are expected to be supported in each of FY 1985 and FY 1986?**

Answer: In FY 1984 and in FY 1985 we estimate that the Nuclear Physics program provided support to approximately 1400 Ph.D. level researchers. In FY 1986, we anticipate a slight reduction from the FY 1984-1985 level.

11. **How much did the Nuclear Physics Program contribute to the support of DOE's Small Business Innovative Research (SBIR) Program for FY 1984? How much is estimated for FY 1985 and FY 1986?**

Answer: In FY 1984, the Nuclear Physics program provided $780,000 in support of the Small Business Innovation Research program. Estimates for FY 1985 and FY 1986 are $1,425,000 and $1,509,000 respectively.

12. **The February 7, 1985 "Holifield Tables" indicate that the IRB Fiscal Year 1986 request for the Nuclear Physics program totalled $233.0 million, including $174.0 million for operating expenses and $59.0 million for plant and capital equipment. According to these Tables, the Department's FY 1986 submission to OMB totalled $226.3 million, including $168.9 million for operating expenses and $57.4 million for plant and capital equipment. What are the specific differences between these two budgets?**

Answer: Specific differences between the Nuclear Physics IRB and Nuclear Physics OMB budget requests are given below.

Nuclear Physics Program
(B/A in thousands of dollars)

	FY 1986 IRB Request	FY 1986 OMB Request	Change
Operating Expenses	$ 174,000	$ 168,900	-$ 5,100
Capital Equipment	18,000	17,000	- 1,000
Construction	41,000	40,400	- 600
TOTAL	$ 233,000	$ 226,300	-$ 6,700

Operating Expenses

The $5,100,000 reduction in the request for Operating Expenses required reduction, by this amount, in a proposed $7 million initiative to: acquire gallium for use in a detector for solar neutrinos; modify the Homestake mine in South Dakota to house this detector; and fabricate a radioactive source to calibrate this detector. The OMB request meant that start of acquisition of the 30 to 35 metric tons of gallium needed for this solar neutrino detector be deferred beyond FY 1986 or that the gallium come from non-DOE sources.

Plant and Capital Equipment

The $1,600,000 reduction in the Plant and Capital Equipment request required elimination of a planned 5% increase in levels of activity over FY 1985 in programmatic instrumentation and minor facility improvements. These planned increases in activity were requested to modernize instrumentation at the Nuclear Physics accelerator centers to meet requirements of experiments projected over the next two or three years.

13. **As noted in question 13 above, the February 7, 1985 "Holifield Tables" indicate that the Department's FY 1986 submission to OMB totalled $226.3 million, including $168.9 million for operating expenses and $57.4 million for plant and capital equipment, and the FY 1986 Congressional request for Nuclear Physics totalled $172.9 million, including $151.9 million for operating expenses and $21.0 million for plant and capital equipment. (a) What was the original OMB passback? (b) What specific items much did the Department appeal to have included in the Congressional request that are not included in the Congressional request? (c) What are the specific differences between these two budgets?**

Answer: Development of the FY 1986 budget was not a traditional or formal process and involved many discussions and informal interim steps. Specific differences between the Nuclear Physics OMB and Nuclear Physics Congressional budget requests are given below:

Nuclear Physics Program
(B/A in thousands of dollars)

	FY 1986 OMB Request	FY 1986 Cong. Request	Change
Operating Expenses	$ 168,900	$ 151,900	-$17,000
Capital Equipment	17,000	14,000	- 3,000
Construction	40,400	7,000	- 33,400
TOTAL	$ 226,300	$ 172,900	-$53,400

Operating Expenses

The $17,000,000 reduction in Operating Expenses was allocated to: a reduction in overall facility utilization from 65% (OMB) to 45% (Congressional); elimination of the proposed initiative for a gallium-based solar neutrino detector, limitation of the FY 1986 Tandem/AGS heavy ion nuclear research effort to accelerator tests and preparation for experiments and provision of little, if any, beam time for experiments; and scientific and technical manpower was reduced 5% below what it would have been with the OMB request level in all Nuclear Physics programs except those at the Tandem/AGS, the new injector at SLAC, and the Continuous Electron Beam Accelerator Facility (CEBAF).

Plant and Capital Equipment

The $33,400,000 reduction in the Construction request meant that construction of CEBAF could not be initiated in FY 1986 (-$31,500,000) and that Accelerator Improvement and Modification projects and General Plant projects should be held at FY 1985 dollar levels (-$1,900,000). The $3,000,000 reduction in Capital Equipment required stretchout into FY 1987 of completion of funding for the initial complement of detectors for the Tandem/AGS heavy ion nuclear research program and for the high intensity, polarized ion source at Duke University. This reduction also meant that research instrumentation activities at the Argonne Tandem/Linac Accelerator System (ATLAS), the Holifield Heavy Ion Research Facility, the Bates Linear Accelerator Center, the Clinton P. Anderson Meson Physics Facility (LAMPF), the Bevalac, and the 88-Inch Cyclotron be held at FY 1985 dollar levels and thus a 5% overall reduction with respect to FY 1985 levels of activity.

14. Given the information in questions 12 and 13 above, what are the specific differences between the Department's FY 1986 IRB and the Congressional request budgets for Nuclear Physics?

Answer: Specific differences between the Nuclear Physics IRB and Nuclear Physics Congressional budget requests are given below:

Nuclear Physics Program
(B/A in thousands of dollars)

	FY 1986 IRB Request	FY 1986 Cong. Request	Change
Operating Expenses	$ 174,000	$ 151,900	-$22,100
Capital Equipment	18,000	14,000	- 4,000
Construction	41,000	7,000	- 34,000
TOTAL	$ 233,000	$ 172,900	-$60,100

Operating Expenses

The $22,100,000 reduction in Operating Expenses required: a reduction in overall facility utilization from 65% (IRB) to 45% (Congressional); elimination of the proposed initiative for a gallium-based solar neutrino detector; limitation of the FY 1986 Tandem/AGS heavy ion nuclear research effort to accelerator tests and preparation for experiments but little, if any, beam time for experiments; and an overall 5% reduction in scientific manpower in all Nuclear Physics programs except those at the Tandem/AGS, the new injector at SLAC, and the Continuous Electron Beam Accelerator Facility (CEBAF).

Plant and Capital Equipment

The $34,000,000 reduction in the Construction request meant that the CEBAF construction project could not be initiated in FY 1986 (-$31,500,000) and that Accelerator Improvement and Modification projects and General Plant projects be held at FY 1985 dollar levels (-$2,500,000). The $4,000,000 reduction in Capital Equipment required stretchout into FY 1987 of completion of funding for the initial complement of detectors for the Tandem/AGS heavy ion nuclear research program and for the high intensity, polarized ion source at Duke University. This reduction also meant that research instrumentation activities at ATLAS, Holifield, Bates, LAMPF, Bevalac, and 88-inch Cyclotron be held at FY 1985 dollar levels and thus a 5% overall reduction with respect to FY 1985 levels. The IRB request would have allowed these research instrumentation activities to exceed FY 1985 levels by about 5%.

15. **Why is the Nuclear Physics Program funding the E.O. Lawrence and Enrico Fermi Awards? Has Nuclear Physics always funded these awards? What has been the source of funding of these awards?**

Answer: The E.O. Lawrence and Enrico Fermi Awards are of general interest to many programs within the Department of Energy. The Lawrence Awards are for recent work in any of the following fields related to atomic energy: chemistry and metallurgy, life sciences, physics, national security, and reactors. Fermi Awards recognize outstanding scientific and technical achievement in the development, use, or control of atomic energy. As a service to the Department, the Nuclear Physics program budgets for these awards.

Over the years, the Atomic Energy Commission, the Energy Research and Development Administration, and the Department of Energy have experienced a variety of reorganizations. However, from their inception, Fermi Award in 1956 and Lawrence Award in 1960, these awards have been budgeted within units whose functions are now part of the Nuclear Physics program.

The Nuclear Physics appropriation for Operating Expenses is the source of funds for the Lawrence and Fermi Awards.

CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY (CEBAF)

16. **Please provide a detailed discussion of the tasks completed in FY 1984 and those ongoing and planned tasks in FY 1985 and FY 1986. Please include a discussion of progress made in assembling the scientific, technical, and management staffs, in R&D on the machine design, in forming users' groups, and in hiring nuclear scientists at SURA universities.**

Answer: The principal milestone for FY 1984 was the signing of the R&D contract between Southeastern Universities Research Association and the Department of Energy on August 3, 1984. This contract is the vehicle for conduct of research and development and architect/engineering activities in support of the CEBAF project and for buildup of the team of skilled personnel who are essential for successful execution of this project.

In the first 5 months of FY 1985, a number of significant accomplishments have already resulted:

(1) DOE's Oak Ridge Operations Office completed an independent internal review of the Total Estimated Cost of the project.

(2) The firm of Daniel, Mann, Johnson, and Mendenhall was selected in December 1984 to conduct architect/engineering work to better define the project's scope, schedule, and total cost. This firm has initiated studies of site geology and groundwater.

(3) A lease-to-purchase contract was let for an on-site VAX computer. This computer will be used for engineering design studies. Delivery is expected in April 1985.

(4) A decision was reached to use DC quadrupole magnets on the accelerator center line instead of pulsed quadrupoles. Detailed studies indicated that no significant degradation of performance would occur in multiple beam operation from this change and significant reduction in operational complexity could be realized.

In the remainder of FY 1985 and in FY 1986, we expect to accomplish the following major tasks:

(1) Research and development contracts, including prototype work, for development of high-power klystrons and modulators will be awarded, and work will be initiated. Prototypes for the high-power klystrons and modulators will be delivered for testing.

(2) Final specifications for the accelerating waveguide will be developed, and a research and development contract for prototype fabrication will be awarded. The prototype accelerating waveguides will be delivered. Low-power RF testing will be carried out.

(3) Architect/engineering activities will be completed through Title II for the tunnels and surface buildings needed to house the linac, recirculator, stretcher ring, and beam transport. A detailed conceptual design will be completed for CEBAF's three experimental areas.

(4) A prototype injection kicker magnet for the stretcher ring will be constructed and tested. Manufacturing specifications will be developed.

(5) A prototype electrostatic septum will be constructed and tested. Manufacturing specifications will be developed.

(6) A prototype RF cavity for the stretcher ring will be fabricated and tested. Manufacturing specifications will be developed.

(7) A contract will be let for fabrication of a prototype pulsed dipole magnet for the beam transport system. The prototype pulsed dipole and its power supply will be delivered and tested. Manufacturing specifications based on these tests will be developed.

A national search is now under way for a permanent director and deputy director. At the March 15 meeting of SURA's Board of Trustees, we expect an announcement of a permanent CEBAF Director and Deputy Director. Immediately after these positions are filled, permanent department heads will be chosen.

The following is a summary of the existing staff and near-term staffing projections:

	Full-time Equivalents as of February 28, 1985	Full-time Equivalents as of December 31, 1984
Management	16.8	25.8
Technical	12.7	19.7
Scientific	3.5	5.5
TOTAL	33.0	51.0

These totals include 17.5 full-time equivalents funded by the Commonwealth of Virginia.

Active and enthusiastic users' activities are growing up around the CEBAF effort. A formal users' group organization was created in October 1983, and a charter has been approved by the members. The present board of directors of this group are:

Hall Crannell, Chairman (Catholic University of America)
Ralph Minehart, Chariman-Elect (University of Virginia)
Raymond Arnold (American University and SLAC)
Jochen Heisenberg (University of New Hampshire)
William Bertozzi (MIT)
Roy Holt (Argonne National Laboratory)

This organization has formed working groups to optimize selection of experimental facilities and spectrometer systems that will be necessary to carry out the experimental program of CEBAF as well as a theory working group composed of theoretical physicists with research interests in the areas to be explored at CEBAF. The various working groups have held working sessions to define the parameters for the spectrometer systems, and an intensive effort is planned for the summer of 1985. It is expected that the product of these efforts will be conceptual designs for the initial complement of experimental equipment. The final detailed design of the spectrometers and associated detector systems would derive from these conceptual design studies.

The creation of new positions in nuclear physics at SURA universities and the recruitment of distinguished scientists to fill them is well underway. As examples, George Washington University has created and filled two new faculty positions, the College of William and Mary one new position, the University of Maryland two positions, Hampton Institute one position, and the University of Virginia four positions. We anticipate that the expansion of nuclear physics faculty at SURA universities will greatly strengthen research and teaching in nuclear physics in the United States.

17. **How many new faculty positions in nuclear physics have SURA universities provided to date?**

Answer: The process of creating and filling with distinguished scientists new tenure and tenure track faculty positions in experimental and theoretical nuclear physics at SURA universities has begun. For example, two new faculty positions in nuclear physics were created and filled at George Washington University, one position at the Hampton Institute, two positions at the University of Maryland, four positions at the University of Virginia, and one position at the College of William and Mary. The process of faculty recruitment is necessarily a somewhat lengthy one since a university must administratively create the position, advertise the position in conformity with equal opportunity regulations, interview the candidates, acquire letters of recommendation, and complete the internal decision-making process. Because of the newness of the CEBAF project, different universities are at different stages in their recruiting efforts.

18. How much funding for CEBAF have each of the SURA universities provided to date?

Answer: Funds listed below include membership fees, annual dues, and any other assessments or contributions from Southeastern Universities Research Association Institutions:

SURA Institution	Funding to CEBAF
University of Alabama at Birmingham	$ 10,000
University of Alabama	9,000
American University	11,500
Auburn University	9,000
Catholic University of America	10,000
Clemson University	10,000
University of Delaware	9,000
Duke University	8,000
Florida Institute of Technology	10,000
Florida State University	9,000
George Mason University	10,000
Georgetown University	10,000
George Washington University	10,000
Georgia Institute of Technology	9,000
Hampton Institute	9,000
James Madison University	9,000
University of Kentucky	7,000
Louisiana State University	10,000
University of Maryland at College Park	15,000
University of Miami	10,000
Norfolk State University	7,000
University of North Carolina at Chapel Hill	10,000
North Carolina State University	9,000
Old Dominion University	15,000
University of Richmond	15,000
University of South Carolina	15,000
University of Tennessee at Knoxville	9,000
University of Virginia	30,000
Virginia Commonwealth University	15,000
Virginia Polytechnic Institute & State University	25,000
Virginia State University	13,000
College of William and Mary	13,000
TOTAL	$ 370,500

In addition to the above support by the member universities, the SURA/CEBAF project has received the following direct support from the Commonwealth of Virginia:

Funding Period	Amount
1982	$ 10,000
1983	160,000
1984 - 1986	2,000,000
	$2,170,000

In addition, since July 1, 1984, the Commonwealth of Virginia has supported 17.5 full-time positions at the CEBAF site through the College of William and Mary. These staff include support personnel such as secretaries, computer programmers, contracts and financial staff, and maintenance people. Also, the facilities of the Virginia Associated Research Campus in Newport News have been leased at nominal charge to SURA by the Commonwealth of Virginia for use in connection with the CEBAF project. This facility is immediately adjacent to the proposed CEBAF site. The estimated value of this facility is $3.5 million. Several member universities have also made contributions to the effort by providing release time for personnel to work full-time on the CEBAF project, by providing free access to computing and accounting facilities, and by providing free space for meetings and R&D activities.

19. **How many individuals are currently working directly on the machine design and the requisite subsystems? Has this effort received an extensive peer review? Will such a community-wide review take place?**

Answer: Thirteen full-time equivalents are currently working directly on machine and subsystem design.

The CEBAF project has received, is receiving, and will in the future receive extensive peer review. The following summarizes reviews in the recent past:

(1) DOE/NSF Nuclear Science Advisory Committee's "Panel on Electron Accelerator Facilities" (April 1983)

-- Reviewed electron facility proposals submitted by five institutions

-- Found the highest priority for new accelerator construction in the U.S. nuclear physics program to be an electron accelerator of high duty factor capable of producing beams at any energy in the range from 500 MeV to 4000 MeV

-- Chose the CEBAF proposal submitted by SURA as having the highest technical merit

-- Full Committee recommended that construction of CEBAF be implemented without delay

(2) DOE/NSF Nuclear Science Advisory Committee's "A Long Range Plan for Nuclear Science" (December 1983)

-- Reaffirmed their earlier recommendation for the earliest possible start on the construction of the 4 GeV CW electron accelerator capability

(3) DOE/NSF Nuclear Science Advisory Committee's "Ad Hoc Subcommittee on a 4 GeV CW Electron Accelerator for Nuclear Physics" (September 1984)

-- Reaffirmed the 4 GeV CW Electron Accelerator as the highest priority nuclear physics construction project

(4) DOE/NSF Nuclear Science Advisory Committee's "Review of the 1983 Long Range Plan for Nuclear Science" (November 1984)

-- Reaffirmed scientific priorities and recommendations of the 1983 Long Range Plan

-- Endorsed again as first priority for new construction a 4 GeV CW electron accelerator

The following are ongoing or planned mechanisms for review of the CEBAF project:

(1) SURA National Advisory Board

-- Reports to the president of SURA and the director of CEBAF

-- Advises SURA and CEBAF on matters of overall laboratory policy

(2) SURA/CEBAF Technical Advisory Panel

-- To be organized at an early date

-- Will report to the president of SURA and the director of CEBAF

-- Will provide independent, expert advice on technical matters relating to CEBAF

(3) Internal DOE Reviews

-- Monthly project reviews by Oak Ridge Operations Office and the DOE Headquarters staff

-- Ad hoc review panels as needed to review specific technical or managerial questions

20. What is the latest cost estimate of the project?

Answer: The present Total Estimated Cost of the CEBAF construction project is $201 million in FY 1986 dollars or $225 million in escalated dollars if an FY 1986 initiation of construction were assumed. Since funds to start CEBAF construction are not contained in the FY 1986 budget request, the estimate in escalated dollars will require reevaluation to reflect the effects of a later start of construction. In addition, approximately $25 million in FY 1986 dollars will be required for research and development and architect/engineering activities in support of the construction project.

CONSTRUCTION

Project 84-R-123, Tandem/AGS Heavy Ion Transfer Line

21. **Please provide a status report of this project.**

Answer: The project includes a 2100 foot beam transfer line from the Brookhaven Double MP Tandem Facility to the Alternating Gradient Synchrotron (AGS) and minor modifications to both accelerators. Upon project completion, the Tandem/AGS accelerator complex will be able to accelerate heavy ion beams up to mass 32 (sulfur) to an energy of 14 GeV per atomic mass unit, seven-fold greater than at any U.S. facility. The total estimated cost of the project is $10.3 million ($5.0 million in FY 1984, reprogrammed from Isabelle/CBA, and $5.3 million in FY 1985). Excavation for the tunnel which will house the beam transfer line is underway. A contract is in place for the beam transfer line magnets. The tandem intershield is installed and undergoing tests. Modifications of the AGS's RF system are in progress. Installation of transfer line magnets is scheduled to begin in July 1985. Project completion is expected in FY 1986. Ten weeks of operation for heavy ion nuclear research is planned for FY 1987.

Project 84-ER-110, University Accelerator Upgrade at the Univerity of Washington and Yale University

22. **Please provide a status report of these two upgrade projects.**

Answer: A superconducting linac booster is being added to the tandem accelerator at the University of Washington, and the tank and high voltage column structure of the Yale University tandem accelerator are being extended. In each case these upgrades approximately double the energy and mass range of the accelerators, thus strengthening the nuclear research capabilities of two leading universities which have a history of training high quality nuclear science graduates. The total estimated cost of the project is $19.0 million ($8.0 million in FY 1984 and $11.0 million in FY 1985). At Yale University ($8.0 million), procurement contracts totaling $4.3 million are in place for accelerator components and the new tank. Disassembly of the existing tandem will begin in July 1985. Project completion is expected in September 1986. At the University of Washington ($11.0 million), fabrication of the superconducting resonators has begun at Seattle. Resonator plating and testing facilities are operational. Project completion is expected in June 1987.

MINORITY QUESTIONS CONCERNING THE DEPARTMENT OF ENERGY'S FISCAL YEAR 1986 BUDGET REQUEST

1. **Considering the constraints on this year's budget requests, and the likelihood these deficit pressures will be with us for some time, can we seriously expect the construction of the next generation of accelerators (i.e., CEBAF and SSC) to be on schedule?**

   Answer: Due to the different status and time scales of the Superconducting Super Collider (SSC) and the Continuous Electron Beam Accelerator Facility (CEBAF) project, I will address them separately.

   No decision has been made to seek funds for the construction of an SSC facility. Once such a decision is made, and after site selection, it will take about six years to construct the facility.

   The facilities presently in operation, and those soon to come into operation, will give the U.S. world-class facility capabilities into the 1990's. However, without new facility capabilities coming into operation by the mid-1990's, the U.S. program cannot continue to be competitive on a world basis. High energy physics is one of the frontiers of basic research and is a developer of new knowledge and also new technologies with broad applications. As such, it is an important national program which has a solid record of achievement.

   The highest priority for new construction in basic nuclear research in the U.S. is the CEBAF project. This project will help maintain our nation's preeminence in an important area of basic science and technology. The Department of Energy will make every effort to keep the CEPAF project on a realistic schedule within budget constraints.

2. **If it is indeed unrealistic to assume we can meet these construction schedules, should we be continuing to spend large amounts of money on preliminary R&D for the SSC and CEBAF?**

   Answer: It is not unrealistic to assume that we can achieve the Superconducting Super Collider (SSC) and the Continuous Electron Beam Accelerator Facility (CEBAF) on reasonable schedules. The R&D studies funded before a commitment to a project is made, explore new technologies and cost-reduction possibilities that help enable us to meet the physics goals in the most cost-effective manner. A well-executed R&D program prior to the start of construction leads to improved performance of the final facility, identifies technical problems at a time when they can be solved with minimum cost, and indicates optimal technical strategies for achieving goals.

3. **If we postpone this R&D and eventual construction of the next generation of accelerators until we have a more favorable economic climate, what impact would this have on our nation's scientific and technological progress?**

   Answer: It is difficult to forecast what the real impact might be. However, it is likely that the impact could be substantial on the nation's science and technology posture as well as detrimental to its economy. These kinds of projects spur the development of advanced technologies and stimulate the transfer of the technologies to industry as well as increase the nation's competitiveness.

4. **International collaboration has been proposed as a means of coping with the high costs of projects like the SSC. Several countries have voiced their interest in participating in such an effort. Does this interest translate into significant monetary contributions? Also, what are the prospects of reaching a consensus on where to locate a facility that is constructed and operated by several nations? Would the U.S. be willing to locate such a facility in Europe and vice versa?**

Answer: We are pursuing the possibilities of international collaboration and cost sharing in the Superconducting Super Collider (SSC) through many channels, including the Economic Summit process for which I am the U.S. delegate. At this early time, there are no commitments from any foreign nations, although there have been expressions of interest. Scientists from around the world have indicated great interest in participating in experiments at the SSC. Foreign contributions to the detectors are a likely form of collaboration and cost sharing.

There also have been discussions regarding the mechanisms for joint construction and operation of accelerator facilities through the forum of the International Committee for Future Accelerators (ICFA). There is a general consensus among the participants in ICFA that the generation of new facilities presently under consideration (including the SSC) should be pursued as national facilities, with international collaboration and cost sharing where appropriate. There is agreement that it is essential to coordinate plans to avoid unnecessary duplication of facilities.

In addition, participants in the Economic Summit process have agreed that it is important to have some facilities with frontier research capabilities in each major region. High energy physics is an exploratory science which needs a continued infusion of new experimental capabilities as the frontier of exploration moves forward. New capabilities anticipated for the U.S. program prior to the SSC are the colliding beam capabilities of the Tevatron and SLC which become available in 1986. These facilities, which will be the strongest U.S. facilities, will be relatively old capabilities by the projected time of operation of the SSC in the mid-1990's. The Europeans, on the other hand, have the two major high energy physics construction projects, the Large Electron-Positron (LEP) and the Hadron-Elekton-Ring-Anlage (HERA), underway whose initial operation is anticipated for 1989 and 1990, respectively, and which have subsequent upgrade prospects. These would clearly still be world-frontier facilities in 1995. I believe that it is impossible to answer the question as to what the U.S. would be willing to do since the decision would have to be based on concrete proposals with the benefits to all parties clearly understood. I am not aware of any proposal at this time.

5. **It is very discouraging to see the utilization levels at our national labs continue to decline. Keeping our budget limitations in mind, are there any institutional changes you could recommend for more efficient use of these facilities? For instance, is closing some labs and consolidating work at others a feasible alternative?**

Answer: We also are concerned about the utilization levels of the high energy and nuclear physics accelerator facilities. Low utilization levels reduce the rate of return to the nation on its capital investment in these facilities.

We are continually alert to possibilities for consolidation and for closing of less productive facilities. We have shut down many high energy and nuclear physics facilities over the course of the last decade as we have moved to the new facilities required to continue advancement of the research. For example, in the high energy program we shut down the 400 GeV program at Fermilab in 1982 as we phased in the Tevatron, and we are shutting down the fixed-target program at SLAC as we bring SLC into operation. In the nuclear physics program, thirteen accelerator facilities have been retired from operation in the last ten years. Each of the remaining high energy and nuclear physics facilities has a unique set of research capabilities which are important to continued progress and our ability to pursue the most important scientific questions.

To optimize the overall scientific productivity of the high energy and nuclear physics program within a constrained budget, we must maintain an appropriate range of experimental capabilities and make use, in a balanced way, of the unique capabilities at each facility. It is essential to maintain an appropriate balance between effective operation of existing facilities for today's research and preparations for the new capabilities essential for future research.

6. **It is a fact that the inflation levels in the New York City and San Francisco areas are much higher that the national average. If this year's DOE request is any indication of the requests to be made over the next few years---with operating expenses being frozen except for modest increases to account for inflation, does it make sense to plan on any growth at facilities located in these areas if we really cannot afford the wages and utility rates unique to them?**

Answer: The Department and its laboratories are working hard to contain and reduce costs. In order to control costs, it is important to make appropriate use of past substantial investments at existing laboratories when possible. For example, in high energy physics, the only source for intense pulsed high energy electron beams in the 50-GeV range is the SLAC linear accelerator and the highest energy electron-positron colliders are at SLAC in Palo Alto, California. Where progress in physics demands further explorations in these particular areas, it is clearly more cost effective to do so at SLAC. To achieve the physics otherwise would require new construction and establishing a major new laboratory or a large addition to an existing laboratory which would surely be much less effective than building upon substantial past investments at SLAC.

To provide the high energy heavy ion accelerator capabilities needed for future research in basic nuclear physics, the most effective approach is to utilize and build upon the excellent facilities already at Brookhaven National Laboratory and Lawrence Berkeley Laboratory. Reproduction of these existing facilities at another geographical site would be unjustifiably expensive and economically counterproductive.

7. **What is being done to improve technology transfer at DOE-supported facilities? We do want to make sure that the benefits of federally-supported research are made available to private industry to the greatest extent possible.**

Answer: The Secretary of Energy has stated in policy guidance to the multiprogram laboratories that a fundamental role of the laboratories is to provide for and encourage the transfer of technology developed at the laboratories to the public and private sectors and facilitate an interactive climate among the national laboratories and industry.

In response to the Stevenson-Wydler Technology Innovation Act of 1980, P.L. 96-480, the Department has required each major laboratory to establish a focal point, an Office of Research and Technology Applications, and to upgrade its interactions with industry. The Department has issued a class waiver policy granting patent rights to users in advance for all inventions when industry has reimbursable work done at our designated user facilities. With this incentive, industry and university interaction with the laboratories increased. The Department has issued guidelines encouraging laboratory professional staff to consult for the private sector. This has stimulated increased person-person interactions between laboratory and university and industry scientists.

Our Departmental patent policy is also responsive to Title V of the Federal District Court Organization Act of 1984, P.L. 98-620, and, in effect, patent rights covering nondefense Federally-supported work at most national laboratories will be made available to the contractors who operate them in accordance with the provisions of that law. As a result, there is already an increased interest in technology transfer opportunities at DOE laboratories.

One of the most effective and proven approaches to technology transfer is the regular exchange of ideas between scientists and engineers. DOE is initiating a new effort, the DOE-Industry Technology Research Program, to support visiting research appointments at the laboratories for scientists and engineers working in industry. The twin objectives of this program are to develop closer working relationships between the DOE laboratories and private industry, and to enhance the transfer of appropriate DOE research and technology to the private sector.

The Department publishes the Research and Development Laboratory Technology Transfer Program Annual Report which highlights technology transfer achievements at the major Department laboratories, lists technology application assessments and technical information program by laboratory, and provides a listing of laboratory program contact personnel. Recent accomplishments have ranged from advances in medical and materials sciences to computer software and technology. One measure of the technology transfer accomplishments of the DOE laboratories is reflected in the number of IR-100 awards received annually. Each year Industrial Research magazine awards, with a citation, the 100 technical innovations with the greatest commercial potential. In 1984, the DOE laboratories alone, received 17 IR-100 awards. (1985 number to be published in September.)

PANEL 1: NEW RESEARCH OPPORTUNITIES

Mr. **Fuqua**. Our next panel will begin on new research opportunities: Dr. George Pimentel, Chairman of the National Research Council Committee to Survey the Chemical Sciences, from the University of California, Berkeley; Dr. Daniel Kleppner, Department of Physics and Research Laboratory of Electronics at MIT; Dr. Frederick Seitz, Rockefeller University in New York City.

George, I believe you're in the middle there.

Dr. Seitz, do you want to join them at the table, there?

I might also say for the members, Dr. Pimentel has already testified earlier this morning before our Task Force on Science Policy, and yesterday he was honored by the President in receiving one of the Science Medals. So again, congratulations to you, and we're very pleased to have you here.

[The biographical sketch of Dr. Pimentel follows:]

Dr. George C. Pimentel

Professor George Claude Pimentel assumed Directorship of the Laboratory of Chemical Biodynamics at the University of California at Berkeley on July 1, 1980 after three years as Deputy Director of the National Science Foundation (1977 to 1980). Dr. Pimentel has been a member of the Chemistry faculty at the University of California at Berkeley since 1949. He is widely known for both his scientific research accomplishments and for excellence in teaching. Dr. Pimentel was elected President of the American Chemical Society. He serves as President Elect during 1985. President in 1986 and Past-President in 1987.

Born May 2, 1922, in Roilinda, California, Dr. Pimentel received a Bachelor of Arts degree from the University of California at Los Angeles (UCLA) in 1943. After a year on the Manhattan Project at the Berkeley campus and more than two years in the Navy, he returned to Berkeley and completed his graduate work. After earning a Doctor of Philosophy degree in 1949, Dr. Pimentel was appointed a member of the faculty at Berkeley and 10 years later he had attained the rank of professor.

From 1966 to 1968 he served as Chairman of the Chemistry Department. He served on the University of California Select Committee on Education in 1965-66. He was a member of the Lunar and Planetary Missions Board, an advisory unit to the National Aeronautics and Space Administration (NASA), from 1967 to 1970 and a member of the National Academy's Committee on Science and Public Policy from 1975 to 1977.

STATEMENT OF DR. GEORGE C. PIMENTEL, CHAIRMAN, NATIONAL RESEARCH COUNCIL COMMITTEE TO SURVEY THE CHEMICAL SCIENCES, PROFESSOR OF CHEMISTRY, UNIVERSITY OF CALIFORNIA AT BERKELEY, BERKELEY, CA

Dr. **Pimentel**. Thank you very much, sir.

It's appropriate for me to begin by stating that I speak today as an individual scientist, not as a spokesman for any particular institution or organization. I will also say, as you will perceive very shortly, that I shall be speaking in a much more parochial vein than I hope I did this morning. But in any event, I thank you for the opportunity to comment on the proposed fiscal year 1986 budget for the Department of Energy.

I sincerely apologize for not submitting an advanced written testimony. I just returned 2 days ago from a 2-week scientific visit to Great Britain; however, this visit proved to be timely and, I think, relevant to these hearings. I was able to speak at length with the chemistry members of their Science and Engineering Research Board and with the head of their Science Board. Their Science and Engineering Research Board can be likened to our National Science Foundation, but it carries broader responsibilities than NSF since it funds all fundamental research. So it encompasses the research areas that appear in the budget you're considering today.

This monolithic organization that they have confronts the British science policymakers much more directly with the need to compare across disciplinary boundaries the relative likelihood for scientific advance and for long-range societal benefit. I encountered this same critical perspective among Swedish policymakers in a similar 2-day meeting in Stockholm last December. It was reassuring to compare notes with these preeminent scientists; they are reaching the same conclusions as we, here.

First, this is a time of very special opportunity for scientific advances in chemistry.

Second, many of the areas of promise underlie future responses to societal needs, surely including those appropriate to the missions of the Department of Energy.

And third, there was agreement on where these opportunities lie.

With that reassurance, I must say, however, it was a bit unsettling to come away with a sense that our foreign compatriots are moving more rapidly than we to exploit the opportunities. My contacts abroad, which also extend to Germany, France, and Japan, suggest that we are more reluctant to disturb habitual funding patterns, even though some discipline areas of great promise and with obvious relevance to societal needs are clearly underfunded.

Chemistry is such an area, and the Department of Energy budget provides a showcase example. I realize that's a provocative assertion, and of course, I intended it so. It's based in the broadest sense on a very simple statistic. Today, 92 percent of U.S. energy use comes from chemistry-based technologies, but less than 5 percent of the DOE budget for its most fundamental research goes to its program of chemical sciences.

Repeating, 92 percent of our energy use is from chemically-based technologies, and 5 percent of its most fundamental research goes to Chemical Sciences. I wish to convince you that this 5 percent figure is incommensurate with the potentiality and the importance of chemistry, relevant to the DOE mission.

What is the DOE research mission? Clearly, it is to assure future access to abundant and clean sources of energy. I emphasize the word future because all Federal support for fundamental research is ultimately justified by its anticipated contribution to the long-range wellbeing of society. As the DOE contemplates this mission, it must reckon with these challenging expectations for the next 3 decades. By the year 2000, U.S. annual energy consumption will exceed today's use by at least 20 percent. Nuclear fission use is hardly growing because of societal concerns. Hydroelectric power has natural limits and involves environmental encroachment costs. Even the most optimistic proponent of nuclear fusion does not see it providing a large fraction of our energy use before well into the 21st century.

And finally, world production of high grade petroleum crudes will begin to decline 15 to 20 years hence as worldwide reserves are depleted and as access to foreign reserves is capriciously restricted by political developments beyond our control.

These boundary conditions surely point to the need for expanding the knowledge base upon which new energy technologies can be built. Chemical and electrochemical systems provide some of the most compact and efficient means of energy storage. We can be confident that 15 to 20 years hence we will still be getting 90 percent of our energy from chemically based fuels. Unfortunately, foremost among the new energy sources will be low-grade chemical fuels such as shale oil, tar sands, peat, lignite, high sulfur content coal, and biomass. For not one of these alternatives does appropriate technology exist today that can economically meet the stringent demand that environmental pollution be avoided despite the higher impurity content of these new feedstocks.

Enormous chemical challenges must be met. We need new catalysts, new processes, new fuels, more efficient combustion conditions, better emissions control, more sensitive environmental monitoring. Combustion of biomass must be brought to practicality as a step toward controlling the rate of increase of atmospheric carbon dioxide. Notice that combustion of biomass cannot return to the atmosphere more CO_2 than was consumed in the photosynthetic reactions by which the biomass was produced.

Solar energy must be fully exploited, including artificial photosynthetic and electrocatalytic techniques that avoid combustion by converting the photon energy directly to electrical or chemical energy.

To accelerate our movement toward meeting these critical needs for the next three decades, the Department of Energy should initiate a major initiative in those areas of chemistry relevant to the energy technologies of the future. It should encompass reaction kinetics. We should exploit the amazing possibilities of lasers and computers for understanding the entire course of chemical reaction. Note that a 5-percent increase in combustion efficiency would be worth $15 billion per year to the U.S. economy, and immeasurable additional value if it were accompanied by a reduction in smog and acid rain.

Catalysis—we should bring to bear on this crucial area the full range of sophisticated instrumental techniques that will permit us to transform it from an art to a science. These extend across the spectrum of catalysis: homogeneous, heterogeneous, electrocatalysis, photocatalysis, and enzymatic catalysis.

Plant sciences—we ought to facilitate our use of natural and artificial photosynthesis, biomass, and genetic engineering of photosynthetic organisms, the better to capture and use solar energy.

This initiative should include these components:

The defined mission of some of our national laboratories should be reshaped to include a major focus on the chemistry areas crucial to energy technologies.

Support of university research programs in energy-relevant areas of chemistry should be raised so as to engage more fully the larger chemistry community in the accomplishment of the Department's mission.

Just a year ago, you will remember, I spoke to you on this same subject. I spoke then in more detail about the many exciting new frontiers of chemistry and their rich potentialities for the Department of Energy. I could add today to that list, but in the interests of time I will not do so.

At this time last year, I urged a small beginning on the initiative I've just proposed. Your response was gratifying, as embodied in your report language, which I quote here: "The committee received convincing testimony"—this is a quotation—"as well as a number of communications from members of the chemical sciences community that there are outstanding new research opportunities in the areas of chemical catalysis and reactivity. The Department should consider these new opportunities and fund those appropriate to its mission within the available funds provided in fiscal year 1985, and consider these opportunities in its budget submissions for fiscal years 1986 and 1987."

I do not believe that the budget before you is sufficiently responsive. I see that the Chemical Sciences Program and the Biological Energy Research Programs are dollar-constant; thus, rather than beginning an initiative that moves us toward the development of chemically-based energy technologies in the future, I find the appropriate programs being contracted by inflationary changes.

I believe the stakes are too great, and the potential benefits to our economy are too significant, to postpone further the beginnings of this important initiative. I say this with full recognition that this is a year in which budget retreats are in order, but the investment needed is quite modest compared to the economic and societal implications it carries.

How much would be an appropriate level at which to begin such an initiative? I believe that a $22 million increment is an appropriate and needed investment in the priority areas I've designated. If this increment is made available, it should be divided appropriately among the existing Basic Energy Science programs that would support catalysis in its full breadth, reaction dynamics, and the plant sciences relevant to photosynthesis.

Times of economic stress are times for difficult priority choices. Times for retreat, perhaps, in some areas, and times for increased investment in areas that will bring us back from economic stress and guarantee a less stressful future. The Department of Energy chemistry programs I have mentioned warrant such an increased investment, and a $22 million increment would be a wise and a prudent investment in our technological future.

Thank you very much for letting me make this statement.

[The prepared statement of Dr. Pimental follows:]

TESTIMONY OF

George C. Pimentel
Professor of Chemistry
University of California
Berkeley, California 94720

Thank you for the opportunity to comment on the proposed FY 1986 budget for the Department of Energy. It is appropriate for me to begin by stating that I speak today as an individual scientist, not as a spokesman for any particular institution or organization. I apologize for not submitting in advance written testimony; I have just returned, two days ago, from a two week scientific visit to Great Britain. However, this visit proved to be timely and relevant to these hearings. I was able to speak at length with the chemistry members of their Science and Engineering Research Board and with the head of their Science Board. Their SERC may be likened to our National Science Foundation but it carries broader responsibilities than NSF since it funds all fundamental research, so it encompasses the research areas that appear in the budget you are considering today. This monolithic organization confronts the British science policy makers more directly with the need to compare across disciplinary boundaries the relative likelihood for scientific advance and for long range societal benefit. I encountered the same critical perspective among Swedish science policy makers in a similar two day meeting in Stockholm last December.

It was reassuring to compare notes with these preeminent scientists abroad because they are reaching the same conclusions as we: first, this is a time of special opportunity for scientific advances in chemistry, second, many of the areas of promise underlie future responses to societal needs (including those appropriate to the mission of the Department of Energy), and, third, there was agreement on where these opportunities lie.

It was unsettling, however, to come away with a sense that our foreign compatriots are moving more rapidly than we to exploit the opportunities. My contacts abroad, which also extend to German, French, and Japanese scientists, suggest that we are more reluctant to disturb habitual funding patterns even though some discipline areas of great promise and with obvious relevance to societal needs are clearly underfunded. Chemistry is such an area and the Department of Energy budget provides a showcase example.

If that seems a provocative assertion, I intended it so. It is based, in the broadest sense, on the simple statistic that today 92% of U.S. energy use comes from chemistry-based technologies but less than 5% of its budget for its most fundamental research goes to its program "Chemical Sciences" (see Table I). I wish to convince you that this 5% figure is incommensurate with the potentiality and importance of chemistry relevant to the DOE mission.

What is the DOE research mission? Clearly it is to assure future access to abundant and clean sources of energy. I emphasize the word future because all federal support for fundamental research is ultimately justified by its anticipated contribution to the long-range well-being of our society. As the DOE contemplates this mission, it must reckon with these challenging expectations for the next three decades:

- by the year 2000, U.S. annual energy consumption will exceed today's use by at least 20%;
- nuclear fission use is hardly growing because of societal concerns;
- hydroelectric power has natural limits and involves environmental encroachment costs;

- even the most optimistic proponents of nuclear fusion do not see it providing a large fraction of our energy use before well into the 21st Century;

- world production of high grade petroleum crudes will begin to decline 15-20 years hence as world-wide reserves are depleted and as access to foreign reserves is capriciously restricted by political developments beyond our control.

These boundary conditions surely point to the need for expanding the knowledge base upon which new energy technologies can be built. Chemical and electrochemical systems provide some of the most compact and efficient means of energy storage. We can be confident that 15-20 years hence we will still be getting 90% of our energy from chemically based fuels. Unfortunately, foremost among the new energy sources will be low grade chemical fuels such as shale oil, tar sands, peat, lignite, high sulfur content coal and biomass.

For not one of these alternatitives does appropriate technology exist today that can economically meet the stringent demand that environmental pollution be avoided despite the higher impurity content of these new feedstocks. Enormous chemical challenges must be met - we need new catalysts, new processes, new fuels, more efficient combustion conditions, better emissions controls, and more sensitive environmental monitoring. Combustion of biomass must be brought to practicality as a step toward controlling the rate of increase of atmospheric carbon dioxide. (Notice that combustion of biomass cannot return to the atmosphere more CO_2 than was consumed in the photosynthetic reactions by which the biomass was produced.) Solar energy must be fully exploited including through artificial photosynthetic and electrocatalytic techniques that avoid combustion by converting the photon energy directly to electrical or chemical energy.

To accelerate our movement toward meeting these critical needs of the next 30 years, the Department of Energy should initiate a major initiative in those areas of chemistry relevant to the energy technologies of the future. It should encompass

Reaction Kinetics - we should exploit the amazing potentialities of lasers and computers for understanding the entire course of a chemical reaction. A 5% increase in combustion efficiency would be worth 15 billion dollars per year to the U.S. economy and immeasurable additional value if accompanied by reduction in smog and acid rain.

Catalysis - we should bring to bear on this crucial area the full range of sophisticated instrumental techniques that will permit us to translate it from an art to a science. These extend across the spectrum of catalysis - homogeneous, heterogeneous, electrocatalysis, photocatalysis, and enzymatic catalysis.

Plant sciences - we should facilitate our use of natural and artificial photosynthesis, biomass, and genetic engineering of photosynthetic organisms better to capture and use solar energy.

This initiative should include these components:

o The defined mission of some of our National Laboratories should be reshaped to include a major focus on the chemistry areas crucial to energy technologies.

o **Support of University research programs in energy-relevant areas of chemistry should be raised so as to engage more fully the larger chemistry community in the accomplishment of the Department's mission.**

Just a year ago, I spoke to you on this same subject. I spoke then in more detail about the many exciting new frontiers of chemistry and their rich potentialities for the Department of Energy. At this time I urged a small beginning on the initiative I have just proposed. Your response was gratifying, as embodied in your report language, which I quote here:

> "The Committee received convincing testimony, as well as a number of communications from members of the chemical sciences community, that there are outstanding new research opportunities in the areas of chemical catalysis and reactivity. The department should consider these opportunities in its budget submissions for fiscal years 1986 and 1987."

I do not believe that the budget before you is sufficiently responsive. I see that the Chemical Sciences program and the Biological Energy Research program operating budgets are dollar constant at, respectively, $79.5M, and $12.4M. Thus, rather than beginning an initiative that moves us toward the development of chemically based energy technologies of the future, I find the appropriate programs being contracted by inflationary changes. I believe that the stakes are too great and the potential benefits to our economy are too significant to postpone further the beginnings of this important initiative. I say this with full recognition that this is a year in which budget retreats are in order. But the investment needed is quite modest compared to its economic and societal implications.

How much would be an appropriate level at which to begin such an initiative? I believe that a $22M increment is an appropriate and needed investment in the priority areas I have designated. If this increment is made available, it should be divided appropriately among the existing Basic Energy Sciences programs that would support catalysis (in its full breadth), reaction kinetics, and the plant sciences relevant to photosynthesis. Times of economic stress are times for difficult priority choices - times for retreat perhaps in some areas, and times for increased investment in areas that will bring us back from economic stress and guarantee a less stressful future. The DOE chemistry programs I have mentioned warrant such an increased investment and a $22M increment would be a wise and prudent investment in our technological future.

TABLE I

Relative Funding of Chemical Sciences Among Eleven DOE Fundamental Research Programs

	Request 1986	% of Sum
High Energy Physics	510.1	32%
Magnetic Energy Fusion	390.0	24%
Biological and Environmental Sciences	186.3	12%
Nuclear Physics	172.9	11%
Materials Sciences*	138.5	9%
Chemical Sciences*	79.5	5%
Nuclear Sciences*	47.4	3%
Applied Mathematics*	29.1	2%
Engineering & Geosciences*	28.2	2%
Biological Energy Research*	12.4	.8%
Advanced Energy Projects*	10.9	.7%
	1605.3	101.5%

* These programs funded under Basic Energy Sciences.

Mr. FUQUA. Thank you very much, George.

We have a vote going on, and people leaving were not in response to your testimony but to the fact that a vote was going on. [Laughter.]

We will take a short recess while we go and approve the Journal of yesterday, and we'll be back and resume. I appreciate your indulgence.

[Recess taken.]

Mr. FUQUA. The subcommittee will resume its sitting, and we will begin with Dr. Kleppner.

[The biographical sketch of Dr. Kleppner follows:]

Daniel Kleppner is Professor of Physics at Massachusetts Institute of Technology where he has been on the faculty since 1966. He was educated at Williams College, Cambridge University and Harvard University. His research is in atomic physics, and his interests include high precision measurements and fundamental constants, highly excited atoms and spin-polarized hydrogen. He is a co-inventor of the hydrogen maser and the co-author of two textbooks and numerous scientific publications. Professor Kleppner is a Fellow of the American Physical Society and the American Association for the Advancement of Science, a former Chairperson of the Division of Electron and Atomic Physics of the American Physical Society, and a member of the Physics Survey Committee and the 1984 Committee on Selected Opportunities in Physics.

STATEMENT OF DR. DANIEL KLEPPNER, PROFESSOR OF PHYSICS, DEPARTMENT OF PHYSICS AND RESEARCH LABORATORY OF ELECTRONICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MA

Dr. KLEPPNER. Mr. Chairman, I appreciate the invitation to address the subcommittee on the opportunities in physics which are relevant to Basic Energy Sciences and also to comment on the activities in the Task Force on Science Policy. I also appreciate that you have a large agenda today and the time is short, so I am going to try to summarize my comments in four points. The written testimony that I have submitted——

Mr. FUQUA. We will make the written testimony a part of the record.

Dr. KLEPPNER. That will provide more details, and I will be glad to answer questions.

The first point that I'd like to make is that there are an enormous number of activities and opportunities in physics which are relevant to basic energy sciences. The Research Briefing Panel of which I was a member, the 1984 Panel on Selected Opportunities in Physics, outlines three areas of opportunities which are particularly relevant to basic energy sciences. One is the laser atomic frontier, another one is on deliberately structured materials, and a third is on biomolecular dynamics and intercellular cooperativity.

But beyond these there are many other opportunities. There are opportunities in surface physics, the study of polymers, the kinetics of phase transitions, liquid crystals, atomic processes with relativistic beams, clusters, precision x-ray spectroscopy, to mention just a few. But these areas give an opportunity for the advance of basic science, for our understanding of the fundamental laws of physics; they can lead to the creation of new materials and new technologies which are terribly important to the mission of the Department of Energy.

The second point that I'd like to make is that to pursue these opportunities, new resources are essential. There are physicists across the country who are anxious and itching to move in these new directions, to pursue these opportunities, but they need adequate support to do it. And there are problems, particularly in the universities, and I would like to address my comments primarily to the problems of carrying out this research in the universities. In doing this I should emphasize that I am talking as an individual scientist, not as a representative of any particular committee.

One of the major problems in carrying forward science in the universities is the problem of inadequate instrumentation. This is a well-known problem; it's been studied many times in the past. A new report which has just been issued by the National Science Foundation once again comes to the same conclusion, and if I can quote from the executive summary, "ninety percent of the department heads surveyed reported that, as a result of lack of needed equipment, there are presently important subject areas in which their research personnel cannot conduct critical experiments."

This is a terribly serious problem for any subject which is experimentally motivated, such as physics. However, the problem is serious not only because it is currently preventing groups from moving forward and pursuing the new opportunities; it is serious because it is a symptom of a more general problem. The fact that the instrumentation was allowed to go out of date resulted from a long period of underfunding for the research groups, that when there are not enough funds available, one has to support basic activities—for instance, support for graduate students, salaries for everyday operating support—and the new instruments just get squeezed out.

But there are many other symptoms of inadequate support. There has been a widespread deterioration of the support services needed for experimental science in universities throughout the country, the specialized shops. In condensed matter physics, the lack of materials preparation centers is a critical problem. So there are many indications that physics in the universities cannot go ahead at the rate which is healthy to assure a proper vitality for pursuing these new opportunities.

Other consequences of the inadequate support are that physicists are spending inordinate amounts of time trying to raise money to keep their projects going, that most small groups are supported by several grants, and the process of shopping around, writing proposals and juggling the budgets to keep the research going is taking an inordinate amount of time of the physicists away from the research and away from the teaching.

The third point that I'd like to make is that these problems affect what I will call small physics, broadly, in the universities. Small physics is physics which is done chiefly by small groups. Condensed matter physics works primarily in this mode; so does atomic and molecular and optical physics. In fact, the large majority of research in the universities is carried out by these small groups.

Now, when one looks at any one of these activities by itself, the visibility in the total march of science may not be terribly high. However, when one looks at the activities of these small groups collectively, they appear as a major force in science in this Nation. It is in these areas that much of our best science is done. These areas train most of the professional physicists in the United States, and these areas generate much of our new technology. Of all the areas in physics, it's generally the areas of small science which are closest to the generation of new technology, so they play a very vital role in contributing to society.

The fourth point that I'd like to raise is a comment on this agenda for the Task Force on Science Policy. I was very pleased to read this agenda; I was very impressed by this document. I feel that the questions raised on the structure and the support of science in this Nation are vital, and that we have to examine how the system as a whole is working.

There is considerable reason for pride in physics in the United States. Dr. Pimentel earlier today said that physics in the United States is the envy of the world, and I think that's true, but it would be very dangerous to be complacent about it, that these problems which I have mentioned just now are serious problems which affect the future of physics.

I would like to conclude by saying that I talk about the need for additional support at a time when budgets are being trimmed with some trepidation. Everyone is concerned about the deficit in the Nation right now. I would like to urge, though, that in the long run the only way we can deal with this deficit is to grow economically; that economic growth in this country is tied to new technology, and that new technology is tied to basic science. Simply because we are having these problems with deficits right now, I believe, makes it all the more urgent for this Nation to take care that the basic research in physics and in other sciences is strong and will continue to be strong in the future.

Thank you.

[The prepared statement of Dr. Kleppner follows:]

PREPARED STATEMENT OF DR. DANIEL KLEPPNER, DEPARTMENT OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MA

INTRODUCTION

These comments relate some of the findings of the 1984 Report of the Research Briefing Panel on Selected Opportunities in Physics and some of my own personal observations. The briefings are prepared annually on topics selected by the Office of Science and Technology Policy under the auspices of the National Academy of Sciences' Committee on Science and Public Policy. They are intended to highlight high-leverage areas where a modest investment could have a particularly large impact on scientific research. A copy of the physics briefing is attached (Appendix A). Of the six topics in the briefing, the following three lie within areas relevant to DOE's programs in Basic Energy Sciences.

RESEARCH BRIEFING TOPICS

PHYSICS AT THE LASER ATOMIC FRONTIER

The laser continues to have a revolutionary impact on atomic and molecular physics. New developments include

-Trapped particles. Ions and atoms can be trapped and cooled to the millikelvin regime by laser light.

-New spectroscopies. Femtosecond light pulses, laser spectroscopy of relativistic beams, and other new techniques are opening new areas for the study of atoms, molecules, and fundamental dynamical processes.

-The creation of new species. Molecular ions and other species that play key roles in combustion can, for the first time, be studied with clarity.

-Matter in intense fields. Multiphoton processes reveal new types of nonlinear behavior and can lead to novel types of photochemical processing.

-New light sources. New techniques are making it possible in the laboratory to generate light in the far ultraviolet to soft-x-ray regime, making practical numerous studies in atomic, molecular, condensed matter, and surface physics.

DELIBERATELY STRUCTURED MATERIALS

New techniques make it possible to create materials found nowhere in Nature. Such materials can extend our understanding of basic physics and the behavior of matter and lead to new techniques. Opportunities include

-Surface, interfaces, and thin films. Films one atom thick can be created and fabricated on a scale finer than 100 Å. Such films exhibit new types of low-dimensional behavior and are likely to have important technological applications.

-Disorder in matter. Materials can be made with "controlled disorder." Examples include spin glasses, materials of alternating amorphous layers, and metastable structures. Such research can lead to better understanding of technologically important materials such as polymers.

-Exotic materials. Crystals can be constructed in alternating layers called superlattices, and these can be modified by tailoring the impurity profiles. These materials can lead to new basic theoretical understanding, as in the discovery of the fractional quantized Hall effect, and can have important technological applications such as high-mobility charge carriers in transistors with unprecedented frequency response.

BIOMOLECULAR DYNAMICS AND INTERCELLULAR COOPERATIVITY

There is growing activity at the interface of physics with chemistry, biochemistry, and biology. Activities include

-Biomolecular dynamics. Biomolecules represent a state of matter different from solids, liquids, and gases. The new understanding of disordered systems such as spin glasses achieved in condensed-matter physics is starting to open the way to understanding the relations between structure and function of biomolecules.

-Transmembrane signaling. Recording the electrical conductance of individual molecular channels makes it possible to start to address the fundamental question of biological behavior.

-Molecular basic information storage. New techniques offer hope of elucidating the molecular features of information storage and signal transmission.

-Intercellular cooperative processes. Recent developments in mathematical physics and nonlinear dynamics give promise of understanding cooperative intercellular processes.

OTHER OPPORTUNITIES

Other topics described in the Report of the Research Briefing Panel on Selected Opportunities in Physics are relativistic plasma waves, cosmology, and nuclear matter under extreme conditions. However, the Briefing describes only a small subset of the opportunities for advances in physics. The Briefing specifically excludes initiatives for large facilities. Additional opportunities for advances in areas related to Basic Energy Sciences include

- -Surface physics
- -The kinetics of phase transitions
- -Organic materials
- -Matter under extreme conditions such as low temperature or high pressure
- -Turbulence and instability
- -The electronic structure of strongly interacting systems
- -Liquid crystals

In atomic, molecular, and optical physics, additional opportunities include

- -Low-energy highly charged ions
- -Atomic processes with relativistic beams
- -Clusters
- -Precision x-ray spectroscopy of high-Z atoms
- -Metrology and high-precision measurement

PRIORITIES IN BIG AND SMALL PHYSICS

There is difficulty in maintaining balance between "big" and "small" physics. "Small" physics comprises broad areas of research pursued by relatively independent small research groups, most often using equipment in their own laboratory but sometimes using central facilities such as sophisticated electron microscopes or large facilities such as synchrotron light sources. It is difficult to judge the needs of any one of the small research fields against the needs for major facilities. However, if the areas of small physics are viewed collectively, it can be seen that small physics

-Produces some of the most important advances in science

-Produces much of our new technology

-Trains over 70 percent of the graduate students in physics in the United States

Judged collectively, the small research groups in physics represent a major force in U.S. science. Research by these small groups today is perhaps more productive than ever, and the opportunities for scientific advance are abundant. However, to pursue these opportunities a number of problems must be overcome. These problems include

-Inadequate instrumentation

-Deterioration of support services in universities

-Decreasing attractiveness of academic careers in physics

An article to appear in the March issue of Physics Today describes the research opportunities in the small-group areas and the steps needed to pursue these opportunities. A preprint is attached (Appendix B). The funding agencies should address the collective needs for support of the small research groups in parallel with the need for major facilities and large programs.

RESEARCH BRIEFINGS 1984

Report of the Research Briefing Panel on Selected Opportunities in Physics

Reprinted from *Research Briefings 1984*, National Academy Press, Washington, D.C.
Copyright © 1984 by the National Academy of Sciences

Research Briefing Panel on Selected Opportunities in Physics

Hans Frauenfelder (*Co-chairman*), University of Illinois, Urbana, Ill.
Mildred S. Dresselhaus (*Co-chairman*), Massachusetts Institute of Technology, Cambridge, Mass.
William F. Brinkman, Sandia National Laboratory, Albuquerque, N. Mex.
Praveen Chaudhari, International Business Machines Corporation, Yorktown Heights, N.Y.
Joseph Cerny, Lawrence Berkeley Laboratory, Berkeley, Calif.
John M. Dawson, University of California at Los Angeles, Los Angeles, Calif.
Harold P. Furth, Princeton University, Princeton, N.J.
Daniel Kleppner, Massachusetts Institute of Technology, Cambridge, Mass.
Alexei A. Maradudin, University of California at Irvine, Irvine, Calif.
Francis M. Pipkin, Harvard University, Cambridge, Mass.
John Schiffer, Argonne National Laboratory, Argonne, Ill.
Watt W. Webb, Cornell University, Ithaca, N.Y.
David Wilkinson, Princeton University, Princeton, N.J.

Staff

Donald C. Shapero, *Staff Director*, Board on Physics and Astronomy, National Research Council
Ellen Williams, *Rapporteur*, University of Maryland, College Park, Md.
Helene Patterson, *Staff Assistant*, Board on Physics and Astronomy, National Research Council
Florence Wong, *Secretary*, Board on Physics and Astronomy, National Research Council
Allan R. Hoffman, *Executive Director*, Committee on Science, Engineering, and Public Policy

The panel gratefully acknowledges assistance in preparing its report from Gordon Baym, Robert B. Palmer, Bruce Partridge, David Schramm, Lee S. Schroeder, Andrew M. Sessler, Charles P. Slichter, and Robert Wagoner. Thanks are also due to participants in a planning meeting to select the topics treated in the Physics Research Briefing; those not named above include Richard Brewer, IBM; Dale Compton, Ford Motor Company; Robert Park, University of Maryland and American Physical Society/Washington; and Robert Richardson, Cornell University.

Report of the Research Briefing Panel on Selected Opportunities in Physics

INTRODUCTION

Physics has been rich in discoveries of fundamental laws of nature. These discoveries have influenced other fields of science from mathematics to biology and medicine and have spawned entire industries. Maxwell's electromagnetic theory, for example, forms the basis for understanding electromagnetic phenomena from waves to plasmas and underlies radio, television, radar, and our industrial power networks and modern communication systems. Quantum mechanics provides a framework for portraying physical reality and underlies all of the natural sciences. It has made possible the invention of the transistor, many of the amazing devices of modern solid state electronics, and the laser. Lasers, in turn, are having a major impact on many areas of science. They are also playing a rapidly expanding role in medicine and broad areas of technology, including communications, manufacturing, and national defense.

The discovery of x rays led to the largest single advance in the history of medical diagnostics. The recently created NMR body imaging technique may mark a comparable advance. From the study of electrical noise in the atmosphere, radioastronomy was born, which in turn provided a dazzling new portrait of the universe. Investigations of the properties of nuclei led to the creation of the nuclear power industry. Numerous other examples could be cited. The benefits to society from basic research in physics have been incalculable.

Recent fundamental advances in physics demonstrate that physics is still in a golden age and has never been more vigorous or more productively interactive with other fields. Progress in physics over the last decade has been remarkable. Puzzles that seemed to present insuperable challenges at the beginning of the 1970s have yielded to powerful and elegant theoretical and experimental techniques. The new insights and accomplishments have not only brought greater unity to the various branches of physics but have also strengthened the ties of physics to other areas of science and opened a vast array of new opportunities. Every part of physics has participated in the advance, as the forthcoming report of the Physics Survey Committee will make clear.

The present report focuses on six areas of special opportunity in physics. In order to find areas in which incremental funding may lead to major advances, a planning group (consisting of the Briefing Panel and others listed above) was convened. From twenty suggestions, the following six were chosen: (1) physics at the laser-atomic frontier, (2) relativistic plasma waves, (3) physical properties of deliberately-structured materials, (4) biomolecular dynamics and intercellular cooperativity, (5) cosmology, and (6) nuclear matter under extreme conditions. Large national facilities and well-established programs were explicitly excluded.

The six areas chosen promise to yield fundamental results of great interest. Many of the areas are likely to advance technology and to produce results with impact on the nation's industries; many can be expected to contribute to national security.

All six areas cut across lines of narrow specialization and link different fields. Progress in any one area can thus be expected to stimulate progress in other fields. Cosmology, for instance, connects physics to astronomy and astrophysics. Biological physics interacts strongly with chemistry, biochemistry, biology, medicine, and pharmacology. Deliberately-structured materials relate fundamental aspects of physics to many fields of technology.

1. PHYSICS AT THE LASER-ATOMIC FRONTIER

The laser continues to have a revolutionary impact in the field from which it emerged—atomic physics. The laser-atomic frontier comprises research opportunities generated by joining laser methods with new techniques in atomic and molecular physics.

Opportunities at the laser-atomic frontier include research with trapped particles; femtosecond (10^{-15} sec) spectroscopy and other new forms of spectroscopy; the study of previously inaccessible atomic, molecular, and ionic species; and the development of novel light sources. Advances in these areas will lead to new tests of basic theory and deepen our understanding of the structure of matter at the atomic and molecular level, including the transfer of energy and the nature of chemical reactions. In addition to high scientific interest, many of these topics are likely to yield technological advances. The opportunities selected include the following.

TRAPPED PARTICLES

Using laser light, it is possible to cool to the millikelvin region ions confined in electromagnetic traps and also to cool and trap neutral atoms. In conjunction with recently developed ultrastable tunable lasers, these developments open the way to major advances in high-precision measurements: frequencies to parts in 10^{16}, masses to parts in 10^{11}, new tests of the isotropy of space, and studies of collective motion in plasmas and gases. Applications include advanced atomic clocks, optical frequency standards, metrology, and communications.

NEW SPECTROSCOPIES

Breakthroughs in the generation of femtosecond light pulses make it possible to take "snapshots" of atoms as they collide or molecules as they react, and to observe fast adsorption and relaxation on surfaces. Femtosecond spectroscopy has applications to fast electron circuitry and high-speed instrumentation. Another new type of spectroscopy is carried out with relativistic particle beams. Using the Doppler effect to shift highly stable laser radiation from the visible into the ultraviolet opens the way to new areas of high-resolution spectroscopy of atoms, ions, and molecules. Scientific objectives include studies of relativistic and quantum electrodynamic effects in highly charged ions, high resolution ultraviolet spectroscopy of atoms and molecules, and new types of photoejection measurements.

THE CREATION OF NEW SPECIES

Lasers can produce new species as well as species that have been inaccessible, such as multiply excited atoms, molecular ions, and clusters. Problems such as correlated electron motion, the evolution of matter from single atoms to the condensed state, and catalysis can be investigated. There are many applications to other sciences and to industrial problems. Studies of ionic species can lead to the design of more efficient combustion engines; catalysis is of enormous importance to chemical processing.

MATTER IN INTENSE FIELDS

Laser methods open the way to the study of matter under extraordinary conditions, such as in intense electric and magnetic fields and powerful radiation fields where nonlinear phenomena and multiphoton processes occur. Studies of multiphoton processes made possible by high-power lasers are expected to reveal new aspects of the interaction of photons with matter, and they may open the way to novel types of photochemical processing and isotope separation.

NEW LIGHT SOURCES

The creation of the excimer laser and the generation of extreme ultraviolet light in supersonic atomic beams are two recent examples of light sources from research at the laser-atomic frontier. Other new sources can be expected, with wavelengths from the infrared to the soft x-ray region. Such sources would be valuable to wide areas of atomic physics, chemistry, condensed matter physics, and biology. Using coherent generation of pulsed laser light, for example, it may be possible to provide very short pulses in the soft x-ray region. This technique may provide a laboratory-based alternative to synchrotron radiation light sources for many applications.

2. RELATIVISTIC PLASMA WAVES

Recently an exciting area of plasma physics has emerged—that of relativistic plasma waves in which the electrons or both electrons and ions have relativistic velocities. Exploration of relativistic plasma waves is expected to elucidate recently discovered exotic astrophysical objects and the acceleration of particles to create cosmic rays. An understanding of relativistic collective electromagnetic phenomena may lead to novel particle accelerators and radiation generators. We sketch below some of the specific ideas that need investigation.

PARTICLE ACCELERATORS

The next generation of high-energy accelerators is pushing existing technology close to the limit. The long-range future of particle and nuclear physics may well depend on the development of new acceleration techniques. In addition, new accelerators in the range of 10 MeV to 10 GeV may find application in physics, other sciences, industry, and medicine.

Plasma Accelerators

Space-charge waves in plasmas can produce electric fields that are orders of magnitude larger than can be generated by any other means, with the possible exception of a laser beam focused in a vacuum. These fields can be larger than the fields that bind electrons to atoms (10^9 volts/cm). Such fields can only be maintained in a plasma because they instantly ionize ordinary materials. In a beat-wave accelerator, space-charge waves are generated by sending through the plasma two intense laser beams with a frequency difference equal to the plasma frequency. The combination of high electric fields and phase velocities close to that of light makes such waves good candidates for the acceleration of particles to high energy.

Grating Accelerators

Another novel method uses a grating of droplets illuminated by a powerful short-pulse laser. The resulting plasma grating generates fields estimated to be of several hundred million volts per cm.

Free-Electron Laser Accelerators

Another possibility for constructing an accelerator is to operate a free electron laser "backwards" in an accelerating mode. A further possibility is to operate a free electron laser "forward" and use the resulting radiation to accelerate particles in a conventional linear accelerator. Both of these concepts pose interesting problems and will require developments in current technology.

Laser Development

All of these accelerating schemes require terawatt lasers with good optical quality and very short pulses (shorter than 1 picosecond). Progress with these approaches could be accelerated by a laser development program aimed toward these requirements.

GENERATION OF ELECTROMAGNETIC RADIATION

The inverse of particle acceleration—radiation by energetic particles in plasmas—is a challenging subject of scientific and potentially practical interest. Bursts of radiation that accompany solar activity and are also emitted from a wide variety of astrophysical objects are poorly understood. Recent observations of radiation from pulsars show that the pulses have γ-ray energies up to 10^{15} eV. Such energies imply that the acceleration process occurs over relatively short distances (of the order of 10^3 km) with accelerating fields larger than 10^7 volts/cm. Relativistic waves may be involved. Closer to home, bursts of energetic particles are generated by solar flares; here again strong electric fields must exist in the plasma. The theoretical and computer modeling tools are now reaching the point where progress in understanding these processes can be made.

In the laboratory, copious radiation, roughly up to the thirtieth harmonic of the plasma frequency, has been observed when relativistic electron beams are injected into plasmas. The generation of electromagnetic radiation by means of free-electron lasers is actively pursued at a number of laboratories. Within the last year, free-electron lasers have started operation—two in the microwave, three in the infrared, and one in the visible range. Further configurations especially suited to different parts of the spectrum could be developed. Moreover, theory predicts that energetic electrons streaming through plasmas with strong density fluctuations should yield radiation similar to that produced in present free electron lasers where rippled magnetic fields are used instead of density ripples. At present there are virtually no controlled experiments to investigate these phenomena. The computational tools to address these problems exist, but the resources for using these tools are generally not available to university researchers.

3. DELIBERATELY-STRUCTURED MATERIALS

Condensed-matter science has a long and continuing history of contributions to basic understanding of physical phenomena. General concepts from this field are bringing greater intellectual unity to physics. Ideas from condensed-matter physics and many-body theory are playing a role in such diverse fields as nuclear physics, astrophysics, and theoretical methods of particle physics. While condensed-matter physics is intellectually a rich and fertile field of inquiry for the basic questions of science, it is also playing a vital role in advanced technology from microelectronics and communications to energy systems.

From the vast range of activities in condensed-matter physics, we emphasize only one area of special opportunity: deliberately-structured materials. By deliberately-structured materials, we mean materials designed by man to have particular structures. Their fabrication may involve controlling on an atomic length scale the compositional or structural arrangements of atoms in one or two-dimensions. The resulting materials possess remarkable properties not otherwise found in nature—properties that, in many instances, present major scientific puzzles.

Not only are these materials likely to raise fundamental questions of physics, but their study will also reinforce the technological base of the nation's most important device-related industries. Conversely, technologies that have led to advances in the fabrication of very-large-scale integrated circuits can be harnessed to create deliberately-structured materials.

Three research areas that are currently of great scientific interest and that are especially likely to advance through the use of deliberately-structured materials are: (1) studies of surfaces and interfaces between specifically designed microscopic structures; (2) investigations of "disorder" in matter that might be understood more deeply through tailoring of its composition or geometrical structure; and (3) studies of novel collective phenomena in "exotic materials."

SURFACES, INTERFACES, AND THIN FILMS

Beginning with an atomically clean and crystallographically defined surface, it is possible to prepare a two-dimensional film only 1 atom thick by deposition of a second material. The film can be atomically smooth or contain crystallographic discontinuities, depending on the structure of the substrate. Its structure can be further modified by pattern etching on a scale finer than 100 Å. Deposition of additional layers of dopants, or of metals, semiconductors, superconductors, or insulators, leads to atomically sharp interfaces of defined structure and composition. The physics of these low-dimensional systems is fundamentally interesting. Furthermore, studies of the electronic, vibrational, magnetic, and transport properties of interfaces are applicable to the technological needs of the computer and energy industries.

DISORDER IN MATTER

There are many approaches to creating materials with controlled disorder. One method is the random dispersion of very small particles of one material in a matrix of a second. Another is the fabrication of alternating amorphous layers, resulting in two-dimensional disorder within the plane of the layers but one-dimensional order perpendicular to the plane due to the stacking of the layers. Spin glasses present a totally different form of disorder in which the atoms may be compositionally ordered but the spin-spin interactions are random. Metastable (i.e., nonequilibrium) disordered structures represent a fourth class of deliberately-disordered materials. All these materials have properties that are intrinsically interesting and important. In addition, insight into the nature of controlled disorder may provide a basis for understanding technologically important disordered materials such as polymers, glasses, and composite materials and may even lead to a better understanding of problems in computation, optimization, and neurobiology.

EXOTIC MATERIALS

The structure of materials can be arranged in many different ways to produce unique physical properties. For instance, it is possible to deliberately construct ordered crystals in arrays of alternating layers called superlattices. The properties of superlattices can be modified in desirable ways by tailoring the compositional and impurity profiles of the constituent layers. Many of the traditional methods of condensed-matter theory must be extended to account for the small size or the lower dimensionality of such systems. New phenomena, undreamt of a short time ago, have been discovered in deliberately-structured materials. Examples include quantization and fractional quantization of the Hall effect. The same class of materials that is actively used to investigate the quantum Hall effect is also being examined by researchers worldwide for new applications in the computer and communication industries.

Needs of the Field

The overwhelming characteristic of this field is its dependence on a strong infrastructure to support a range of activities from materials preparation and characterization to study of the nature and causes of unusual materials properties. The infrastructure, involving skilled technicians and complex, state-of-the-art apparatus and instruments, does not exist in most universities; and the institutional mechanisms to put the structure in place at universities are often lacking. The intellectual concepts are there to be exploited if the university infrastructure can be enhanced.

4. BIOMOLECULAR DYNAMICS AND INTERCELLULAR COOPERATIVITY

The magnificent complexity of life that we study as biology ultimately reflects underlying physical principles. At each level—biomolecules, supramolecular structures, cells, and organisms—the behavior of the system is governed by physical laws. The detailed description of biological phenomena in terms of physical laws promises to yield rich dividends both in terms of understanding life more deeply and in exploring the physics of complex systems. Research on biological systems connects physics to chemistry, biochemistry, biology, and, ultimately, pharmacology and medicine. The systems under investigation are, of course, the same in all these fields, but the approaches to them are different. The physicist selects the simplest available system, performs quantitative measurements, constructs a model, and attempts to describe the observed behavior fully in terms of known physical laws. The following examples, at different levels of complexity, indicate where this approach is beginning to bear fruit.

Biomolecular Dynamics

Proteins and nucleic acids, the building blocks of life, were called "aperiodic crystals" by Schrödinger. Seen by standard x-ray diffraction, they indeed appear to be like crystals with linear dimensions of a few nanometers. In recent years, however, a far more exciting picture has emerged. Biomolecules are dynamic systems that represent a state of matter different from solids, liquids, and gases. They show many similarities to glasses and spin glasses but are far more sophisticated. The sophistication is not surprising; each biomolecule has undergone more than 10^9 years of research and development and is built for a particular function. A protein, for instance, must have precise mechanical, electrical, thermal, and chemical properties. These properties are not spatially homogeneous but rather vary throughout the protein volume. Through genetic engineering, proteins with atomic modifications in desired places can be produced. The entire field of physical studies of biomolecules is at its very beginning, but the importance and the potential of such studies are increasingly evident. Biomolecules are excellent laboratories for the investigation of basic physical laws. We can study elementary excitations, motions, transport phenomena, and elementary reaction steps. Biomolecular physics overlaps the physics of glasses and spin glasses and complements the chemistry of reactivity, catalysis, and life processes. With increasing knowledge of the relation between structure and function, it will become possible to design and synthesize biomolecules with desired properties for uses in biological research, medicine, and pharmacology. It is also likely that an understanding of the relation between structure and function of biomolecules, together with genetic engineering, will produce spectacular results in other areas. Biosensors have the potential of improving equipment from medicine to information transfer. New biomaterials, such as biomolecular catalysts and artificial photosynthetic systems, may find uses in areas ranging from agriculture to space.

TRANSMEMBRANE SIGNALLING

Transmembrane signalling is conspicuous in brain, nerve, and muscle tissue. Its molecular basis is now directly accessible through a new biophysical technology: recording of the stochastic electrical conductances of individual molecular channels isolated in very small patches of cell membranes or reconstituted into model membranes. Switching of transmembrane currents through molecular channels is controlled by neurotransmitters, messenger molecules, or membrane potential changes. Hundreds of distinguishable membrane channels and nearly as many neurotransmitters have been discovered. How are channel protein conductances switched by binding of a neurotransmitter? How is ion selectivity built into the protein structure? These profound questions and the biological behavior and disorders associated with them appear susceptible to solution with the help of a combination of gene manipulation and biophysical measurements.

MOLECULAR BASIS OF INFORMATION STORAGE

Elegant experiments on the organization of elementary learning and memory in simple animals at the cellular and molecular level imply a variety of basic signalling processes. The molecular basis of memory is, however, still not understood. The combination of advanced biophysical techniques, such as sensitive optical and electron microscopy probes, with hybridoma techniques for producing monoclonal antibodies, offers hope of elucidating the molecular features of information storage and signal transmission. Prospects are good for understanding the molecular mechanisms of auditory transduction and tone discrimination and the mechanism of visual signal transmission from the photoreceptor. A new family of sensors may develop from these biophysical experiments with some hope of revolutionizing the tools of clinical medicine.

INTERCELLULAR COOPERATIVE PROCESSES

Recent developments at the interface between physics and mathematics have generated new analytical concepts dealing with discrete and nonlinear systems. These systems often display regimes of solution characterized by solitons, limit cycles, disorder, and chaos. These concepts represent many intercellular cooperative processes and have provided understanding of several systems, such as the cooperative heart muscle cell contraction in the heart beat and its failure in ventricular fibrillation.

Physicists have generated new conceptual models of distributed memory. These models, while speculative at present, may, if successful, find ultimate applications in robotics and computer architecture. The theory reproduces many of the foibles and perhaps some of the strengths of the human memory.

5. COSMOLOGY

Few areas of science enjoy as wide an appeal to scientists and laypersons as cosmology. Fascination with the origin and fate of the universe is deeply imbedded in the human intellect, and speculations about these ultimate questions have stimulated some of the most profound thinking in modern science. As in all other scientific disciplines, the basis of cosmology lies in experimental observations. Accurate measurements of the abundances of light elements, for example, fit the specific predictions of a "hot big-bang" model for our universe. Light nuclei were formed when the universe was a few minutes old and had a temperature of 10^9 K—a fantastic extrapolation of known physics. The same hot big-bang model predicted the 3 K cosmic radiation a decade before its discovery.

COSMOLOGY AND PARTICLE PHYSICS

Though uniquely successful in explaining these fundamental observations, the hot big-bang model by itself fails to explain others.

- Why is our universe so asymmetric in matter and antimatter?
- Why is the ratio of baryons to photons in the universe $\sim 3 \times 10^{-10}$?
- Why is the kinetic energy in universal expansion so nearly equal to the universe's gravitational potential energy at the current epoch?
- How did the universe reach the same temperature to a part in 10^4 at points not causally connected?

Two recent ideas from particle physics may answer these fundamental questions and still fit into the basic hot big-bang picture. Grand Unified Theories (GUTs) when applied in the very early universe (age $\sim 10^{-35}$ sec) supply answers to the first two questions. Thus, laboratory tests of GUTs (e.g., by means of proton-decay experiments) may also resolve important cosmological problems. The last two questions above may be answered by a model in which the universe expanded exponentially for a brief time early in its history. This "inflation" is supposed to have been driven by the vacuum energy of a scalar field perhaps related to the Higgs particle that is required by the new theories of electromagnetic and weak interactions. We can, of course, turn the arguments around. Already cosmological data are constraining and guiding GUTs, making the early universe effectively a particle physics laboratory.

WHAT LIES AHEAD?

The long-awaited evidence to describe the fate of the universe could come from either of two lines of attack. One approach attempts to measure directly the deceleration of the universe over the past few billion years. The other approach looks for "invisible" mass density that might eventually reverse the current universal expansion, leading to a hot recollapse. Massive neutrinos, axions, and other exotic particles are under active study in this context by particle physicists and cosmologists. Primordial nucleosynthesis has recently advanced a strong argument against the existence of a large component of dark matter in baryonic form; thus, the search for an exotic mass component has intensified.

Another area of current excitement is the origin and development of large-scale structure—galaxies, clusters of galaxies, etc. The structure seen today is assumed to grow from density perturbations in the early universe. However, observational limits on fluctuations in the thermal background radiation at small angular scale severely constrain models for the origin of structure. Most models that lead to the observed matter clumping also predict fluctuations of the radiation exceeding observed limits. The standard picture must be modified and extended.

Cosmology is at present ripe with opportunity and certain to be full of surprises. The combination of the space program with major advances in astronomical instrumentation is rapidly pushing our horizons deeper into the universe across a wide range of the electromagnetic spectrum. Theory, drawing on all areas of physics, is creating a plausible and testable cosmological model rich with beautiful physics and unanswered questions.

6. NUCLEAR MATTER UNDER EXTREME CONDITIONS

Until recently the study of nuclear matter was restricted to normal values of density and low temperature. With the acceleration of heavy nuclei to relativistic energies, an important new dimension has been added to these studies, namely, the ability to deliver unprecedented amounts of energy and momentum into the volume of the colliding nuclei, a volume large relative to that of a nucleon. With this tool a new era for studying nuclear matter opens up; for the first time we can test the response of such matter to extreme conditions of energy density and compression.

SCIENTIFIC OPPORTUNITIES

Central nucleus-nucleus collisions at high energies open up new avenues that cross the traditional boundaries of particle, nuclear, and astrophysics. The broad goals of such a program—to explore the cooperative behavior in extended hadronic systems with many interacting degrees of freedom—are complementary to those of particle physics in the same sense that condensed-matter physics, with its varied and often unexpected phenomena, transcends the underlying atomic physics. The salient difference is that nuclear studies can themselves shed light on the incompletely understood mechanism of confinement in the basic quantum chromodynamic theory.

Foremost among the opportunities is the possibility of producing a new state of matter called the quark-gluon plasma. Through numerical lattice-gauge calculations, quantum chromodynamics predicts that confined hadronic matter, in which quarks are bound together to form baryons and mesons within the nucleus, will cease to exist at sufficiently high values of compression or energy density. A new phase of matter appears in which the quarks and gluons are freed from the confines of the hadrons. Current theoretical estimates and extrapolations of existing data indicate that the phase transition can be explored in at least two distinct domains accessible in heavy-ion collisions. The domain of *maximum nuclear compression* is a baryon-rich environment expected to occur at energies of a few GeV/nucleon in the center-of-mass frame. In this domain, the heaviest nuclei can still stop each other completely. Densities up to 10 times that of normal nuclei should occur; such densities may be achieved through enhancement of existing accelerators. The domain of *high-energy density* is expected to occur in the central rapidity region left after the colliding nuclei pass through each other at energies of several tens of GeV/nucleon in the center-of-mass frame. Exploration of this domain, expected to be meson-rich with energy densities in excess of 10 times those of ordinary nuclei, awaits construction of future accelerators.

Colliding very heavy nuclei at relativistic energies allows one to study new states of matter and to map out the equation of state of highly compressed/excited nuclear matter, while providing the first indications of the dynamical behavior of extended regions of matter under the most extreme baryon and energy densities accessible in the laboratory.

Suitable facilities will soon be available for accelerating light ions to the 15-225 GeV/nucleon range. These new capabilities are in the region expected to yield maximum nuclear compression and to provide an important extension of our studies of nuclear matter under extreme conditions.

By their very nature, these complex experiments present a major challenge to experimentalists. Detector requirements are similar to those found in particle physics but with a high degree of detector segmentation and enhanced particle identification because of the large numbers of particles expected. Research and development efforts on these detectors are needed so that we will be adequately prepared to measure the complex event structures expected in these interactions.

In nuclear theory, substantial efforts are required to produce theoretical benchmarks for comparison with experimental results. Examples include large Monte Carlo intranuclear cascade calculations and lattice-gauge calculations with inclusion of finite quark masses and finite baryon densities.

IMPACT ON OTHER AREAS

In addition to potential technological spinoffs from the development of new detectors, research on central high-energy nucleus-

nucleus collisions links nuclear physics to other fields. Information gained about the transition from the quark-gluon plasma to hadronic matter is important to cosmologists for understanding how the present state and distribution of matter in the universe evolved. Data from the regime of maximum compression are required to understand the state of matter in the deep interior of neutron stars. There is no other way such information on the high-density equation of state and other properties of matter vital for condensed-matter astrophysics can be obtained in the laboratory. These data will facilitate the interpretation of observations from future orbiting x-ray telescopes such as the AXAF and will help to unravel questions about the birth and evolution of neutron stars. Particle physicists have been studying the short-range behavior of quantum chromodynamics and processes of quark confinement; high-energy nuclear collisions will allow us for the first time to investigate the long-range behavior of this theory and the processes of deconfinement.

CONCLUSIONS

The six areas selected in the present report comprise only a small part of physics. But they exhibit clearly the characteristics of physics—enormous diversity, the search for fundamental laws, strong connections to many other sciences, and technological and industrial applications. Each of the six areas is at a stage where incremental funding may produce major progress. The reasons for the high leverage vary from one area to another, but in each area, there could be rapid progress through meeting a need either for seed funding to promote new research or for new instrumentation, especially medium-cost instrumentation for university research laboratories. Several of the subjects—relativistic plasma accelerators, cosmology, and parts of biophysics—do not have established mechanisms for support and review.

The new areas within nuclear physics, biophysics, and cosmology described above are each in their infancy; exploiting the opportunities to do new forefront physics addressing fundamental questions about matter, life, and the universe could be greatly accelerated by a modest investment of seed money.

Each of the new areas within atomic physics, plasma physics, and condensed-matter physics described above has a need for medium-cost instrumentation that is difficult for university laboratories to obtain within existing funding frameworks. An increment of funding targeted to the instrumentation problem in these areas could unleash untapped scientific productivity in areas with potential applications to technology and national security.

APPENDIX B

Research in small groups

Small-scale research plays a vital role in advancing physics, in training physicists and in generating new technologies, but we will need a new perspective to judge its needs alongside those for large facilities.

Daniel Kleppner

In Munich's Deutsches Museum one can come upon an Italian Renaissance study, meticulously recreated and handsomely furnished save for one intrusion: A plank, one end propped on a trestle, the other resting on the floor. With such a crude apparatus and using his pulse to clock how long a brass ball takes to roll various distances, Galileo first explored the nature of uniformly accelerated motion. With the aid of these measurements he discovered the basics of dynamics; in so doing he also established a tradition for experimental research that has animated physics ever since.

Galileo created the style of a scientist who devises his own experiment, builds his own apparatus, takes his own data and draws his own conclusions. This is the style of Newton and Cavendish, of Fraunhofer, Faraday and Michelson, of Helmholtz, Roentgen, Rutherford and Millikan.

With the invention of accelerators, plasma machines and other large-scale facilities for research, a different style emerged—"big" physics—in which scientists conduct research in large groups and use facilities that are constructed and operated by others. Such research has generated some of the most exciting advances in physics during the past decades. However, the tradition of physics on a small scale—"small" physics—is also very much alive. Today's small-scale research is generally pursued in small groups rather than by individuals, and even the conceptually simplest experiments are likely to require complex and costly equipment. Nevertheless, this tradition has its share of the triumphs in physics.

This article attempts to describe the scope of small-scale research in the advance of physics and to show its role in training physicists and generating new technologies. It will discuss the increasing problems that face small research groups—particularly in the universities—and that give cause for concern about the future of this style of research in the United States. It will then propose a fresh perspective that can provide a useful starting point for addressing these problems.

Because of its diffuse nature and varied goals, one could easily overlook physics on the small scale in viewing the enterprise of physics. But, as we shall see, one would overlook much of the best and most valuable of contemporary science, for this research plays a major role in the advances of physics. If the Nobel prize can be used as a guide to what is important and enduring in physics, it is in the areas of small-scale physics that much of the scientific action takes place. Furthermore, these are the areas where physics most frequently interacts with the other sciences and where it has the most direct impact on our national programs and on industry. Thus, viewed collectively, the independent groups assume a clear identity. These groups produce a large fraction of our best science, train over 70 percent of our graduate students and generate much of our new technology.

Big and small physics

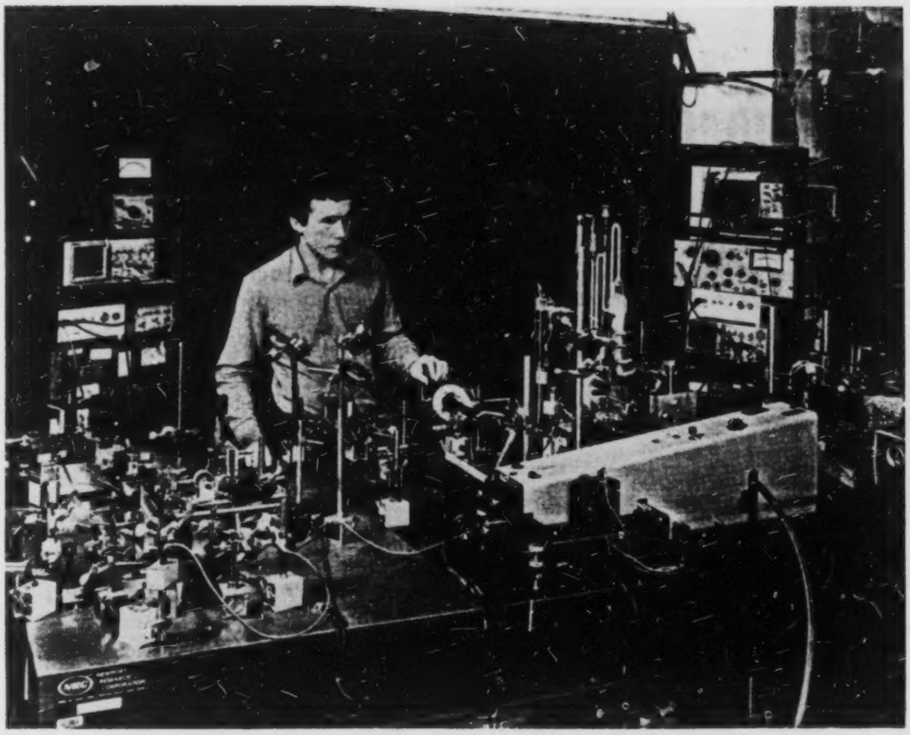
The distinction between big and small physics stems not from their separate scientific goals but from the experimental style required for effective research. The frontier of particle physics—the archetype of big physics—lies at the highest possible energy that can be attained: Nearly all the experimental research must be carried out by large groups using giant accelerators. The frontiers of condensed-matter physics—the major field of small physics—lie in the study of materials by various types of spectroscopy and other techniques requiring small instruments: Such research is most effectively carried out in small groups. Atomic, molecular and optical physics also thrive in the small-group style, as do portions of nuclear physics, astrophysics and plasma physics. Fluid physics, acoustics and all of the "interface" areas, such as biophysics and medical physics, also belong to small physics.

Small-scale research sometimes requires large user facilities. Synchrotron light sources, for instance, are generally used simultaneously by many small groups. Each group sets its own research goals and supplies its own equipment; usually this research constitutes only one portion of the group's program.

One telling indicator of the difference between small and big physics is the number of authors contributing to a scientific paper. The average number of authors for a *Physical Review Letter* in condensed-matter physics is less than three; in particle physics it is more than 40.

In the United States, small-scale research in physics is organized around approximately 1800 independent groups, some as small as a single faculty member with one graduate student, or an experimenter with a few colleagues in a government or industrial laboratory. Many of these groups are relatively free to shift their goals as

Daniel Kleppner is professor of physics in the department of physics and the Research Laboratory of Electronics at the Massachusetts Institute of Technology.



Laser spectroscopy. Frans Alkemade with an apparatus for measuring the two-photon 1s-2s transition in atomic hydrogen by high-resolution Doppler-free spectroscopy in the laboratory of Theodor Hansch at Stanford. The goal of this experiment is to obtain new values for several fundamental constants, to investigate the limitations of QED in atomic hydrogen and to advance the resolution and accuracy of optical spectroscopy. (Courtesy of Theodor Hänsch.)

0031-9228 / 85 / 0300 78-08 / $01.00 © 1985 American Institute of Physics

Submicron machining It has become possible to fabricate devices in the submicron range in which properties of matter are altered qualitatively because of quantum effects. Brian Whitehead is shown here operating a scanning-electron-beam microfabricator in the National Research and Resource Facility for Submicron Structures at Cornell University. The machine is used in the fabrication of superconducting tunneling junctions having an area of 10^{-10} cm^2. Robert A. Buhrman and his colleagues have used such junctions to measure nonequilibrium electron effects in one-dimensional geometries and to study macroscopic quantum tunneling. (Courtesy of Robert A. Buhrman.)

scientific opportunities unfold, and are flexible enough to move rapidly in new directions. Independence is the hallmark of this flexibility, and the research could reasonably be described as "independent group research."

Progress in small physics

A comprehensive description of small-scale research would require summarizing a large portion of contemporary physics; such a task would require volumes. However, it is possible to convey the nature of at least some of this research by sketching a few of the advances.

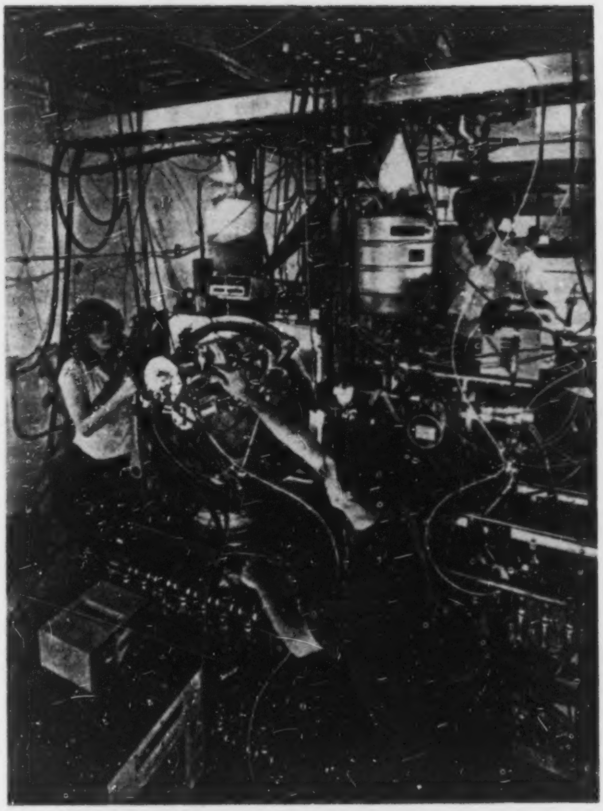
Small physics progresses by numerous experimental discoveries and the close interplay of experiment and theory. For example, meticulous studies of phase transitions in systems ranging from ferrites to gels have culminated in the creation of a fundamental theory of phase transitions—the renormalization-group theory. Experimenters have created new states of matter: a superfluid Fermi liquid, compounds in which electrons simultaneously occupy two valence states, one- and two-dimensional systems, new phases of liquid crystals and many others. Discoveries include the quantized Hall effect—two-dimensional quantum-mechanical phenomena manifested by real materials—and the fractional Hall effect—the signature of a totally unexpected electron gas condensate (see PHYSICS TODAY, June 1981, page 17 and July 1983, page 19). The development of techniques to create controlled disordered systems such as spin glasses has led to a new appreciation of random systems and the first clear picture of motion in random potentials. The discovery of new nonlinear phenomena, such as solitons and strange attractors, has vastly broadened our understanding of nonlinear dynamics and has found applications in topics as diverse as atmospheric turbulence, population dynamics and ventricular fibrillation.

Lasers have revolutionized spectroscopy. They have made it possible to create and study large classes of atomic and molecular systems and to witness multiphoton processes never before seen. Molecular ions, which play key roles in both interstellar chemistry and combustion, have for the first time been studied comprehensively. The flow of energy when two molecules collide can now be traced at the quantum level. New techniques for studying single electrons and ions allow measurements of the fundamental constants with unprecedented sensitivity and precision.

Small physics plays a central role in generating and elucidating fundamental physical and mathematical concepts. The renormalization-group theory, for instance, uses techniques developed in relativistic field theory. Out of this work grew the modern theory of phase transitions and fluctuations. The theory of phase transitions, in turn, is an essential ingredient for understanding the earliest stages of the universe as taken from contemporary ideas in cosmology, particle physics, and statistical mechanics. To cite another example, the concept of broken symmetry was developed independently in condensed-matter physics and particle physics. The acquisition of mass by a particle in a state of broken symmetry is manifested in superconductivity through the Meissner effect; in gauge theories it is manifested by the Higgs mechanism.

Some of the most demanding tests of quantum electrodynamics lie in extremely precise measurements in atomic physics. The interplay of experiment and theory in this area represents one of the most relentless confrontations of experiment and theory in all of physics. Quantum electrodynamics is the prototype of gauge theories; the search for its limits of validity bears on our understanding of the electroweak theory, quantum chromodynamics and other gauge theories. Other precision experiments have set limits on the isotropy of space, the possible breakdown of symmetries such as time-reversal invariance, and the validity of the principle of equivalence.

Technical as well as conceptual links join small physics to other areas of science. Magnets developed from research on high-field superconductors have made possible a new generation of accelerators. Atomic clocks are essen-



Molecular physics. Yuan T. Lee (background), Laurie Butler (left) and Alec Wodtky at Lawrence Berkeley Laboratory are shown with an apparatus used to measure the energies of the fragments of a molecule when it is dissociated by laser light. Such photofragment spectroscopy allows the study of molecular reactions starting from a moment when the reacting species are close together in a precisely defined quantum state. (Courtesy of Yuan T. Lee.)

tial in very-long-baseline radioastronomy; laser interferometers have opened the way to a new class of gravitational-wave detectors. Laser light-scattering spectroscopy is being applied to problems in physics, chemistry, biology and medicine.

These examples, which are drawn from only a few of the many active fields of small physics, illustrate the importance of discoveries in small-scale research to the advance of physics. These examples do not, however, begin to suggest the scope and rapid development of new front-line areas. Many subfields have sprung into existence or have rapidly grown into major research areas within the past decade. The list includes:

▶ *Surface physics.* A host of new techniques has opened the way to studying surfaces and surface phenomena: ultra-high-vacuum methods, tunneling microscopy, x-ray scattering from synchrotron sources, ion scattering, supersonic helium scattering and laser spectroscopy. There have been comparable theoretical advances, some resting on new numerical techniques. The research is advancing rapidly on the structure and excitation of surfaces, surface reactions and catalysis.

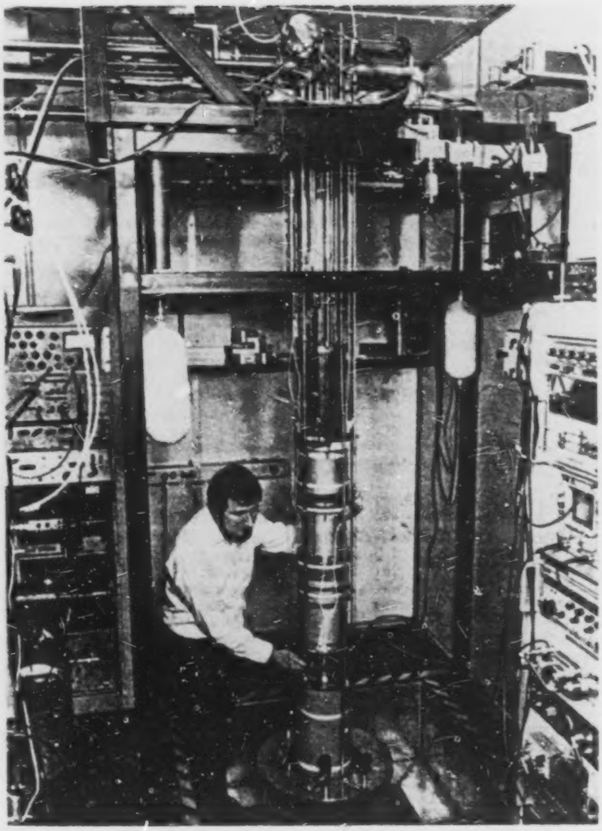
▶ *Artificially structured materials.* Molecular beam epitaxy and other techniques make it possible to create materials that are controlled on the atomic scale: superlattices composed of alternate layers of ordered crystals, amorphous layers that are disordered in two dimensions but ordered in the third, and systems that are effectively one-dimensional, such as those obtained by ion milling and other submicron machining techniques. Such materials, have properties found nowhere else in nature.

▶ *Clusters.* Using supersonic molecular beams, it is now possible to create clusters of atoms or molecules in sizes up to hundreds of particles. These clusters provide the opportunity to observe how matter organizes itself as it evolves from single particles into solids, and how atomic and molecular properties manifest themselves in condensed matter. With metal clusters we can see how band structures develop with increasing size, and we can witness catalytic and other surface phenomena.

▶ *Femtosecond spectroscopy.* Light pulses as short as 12 femtoseconds (12×10^{-15} seconds) have been generated, allowing the observation of the dynamics of molecules and solids at time scales never previously approached. In principle, one can take a "snapshot" of a molecule while it vibrates, witness how electrons in a semiconductor equilibrate or see how chemical reactions take place in solutions and in biological systems.

▶ *Nonlinear optics.* Nonlinear optical techniques have opened new areas in spectroscopy and have also made it possible to study atoms and molecular collisions in ways never before possible. Multiphoton processes, ultrasensitive detection, optical harmonic generation and laser cooling of atoms and ions are some of the advances made possible by nonlinear techniques.

▶ *Polymer physics.* The new ideas emerging from the theory of phase transitions and critical phenomena, combined with such experimental methods as laser light-scattering spectroscopy, nuclear magnetic resonance



Ultra-low-temperature physics. Dilution refrigerators have extended the frontiers of low-temperature physics into the submillikelvin region. This cryostat, shown with Douglas Osherhoff at AT&T Bell Labs, can reach temperatures of less than 100 μK. The cryostat is currently used to study the A_1 phase of superfluid He^3 and nuclear antiferromagnetism in solid He^3. (Courtesy of Douglas Osherhoff.)

and neutron scattering, have profoundly affected our understanding of the processes of polymerization and self-assembly of natural and synthetic macromolecules. These systems, consisting of polymers, micelles, macroemulsions and liquid crystals, are of central importance in many industrial, biological and physiological processes.

This "sampler" should give some idea of the great breadth and rapid progress in small-scale research. A broader portrait of these activities will be presented in the volumes of the *Physics Survey* that will be published shortly by the National Academy of Sciences and the National Research Council.

Impact on society

To appreciate the impact on society of research in small physics one need only think of what the world would be like if the transistor had never been developed. It would be a world without microprocessors, computers and the vast network of data-processing equipment on which science, governments and businesses depend, a world without instantaneous global communications and without the countless feedback and control devices that are essential to everything from jetliners to pacemakers.

Many of these developments emerged from basic research by small groups in industrial laboratories. These laboratories account for about 30% of the basic condensed-matter research in the United States. The strong coupling between industrial and university groups is one of the strengths of these research communities in the US, contributing to the advance of basic physics and the creation of new technologies.

Technology. The returns to society from small-group research can be prodigious. For example, magnetic-resonance imaging is widely regarded as the most important advance in medical diagnosis since the discovery of x rays. Magnetic-resonance imaging was made possible by research on nuclear resonance in chemical and biological systems, the development of superconducting magnets, theoretical research on tomography and image reconstruction, advances in numerical processing and high-speed data-processing devices, and, underlying it all, the discovery of nuclear magnetic resonance decades ago.

The laser has had an enormous impact on science and society. Today these devices are employed in nearly every area of physical science, as well as in the biological sciences and in medical research and therapy. Remote sensing with laser light is used to monitor pollutants, to analyze combustion and to study the atmosphere; laser metrology is used for high-precision surveying, for aligning accelerators and highways, and for controlling scientific instruments and machine tools.

The laser and modern optics play major roles in technology and industry. Fiber-optic cables are revolutionizing data transmission and long-distance communications. Laser printing has become a multibillion-dollar business. Laser-assisted manufacturing is increasingly employed in industry. Laser machining is ideally suited to robotics; it has been estimated that within a decade lasers will be involved in 30% of all the manufacturing operations in the US.

In addition to contributing to basic understanding of nature, small physics is vital to our national programs in defense, energy and the environment.

Education. Over half of the nation's PhDs in physics are trained in condensed-matter physics and atomic, molecular or optical physics. When the other small research activities are included, the fraction is over 70%. Thus the nation depends on small research groups to train most of the physicists who will carry forward basic research, execute the national programs and generate the new technologies that are essential to industry.

Students who carry out an experimental thesis in one of the independent groups usually acquire expertise in many areas. In atomic physics, for example, it is not unusual for a student to become highly skilled in mechanical and vacuum design, electronics, optics and lasers, computer hardware and software or numerical analysis; the student may also have acquired specialized skills in molecular-beam techniques, charged-particle optics or cryogenics. Other fields involve a different mix of skills, but every field of physics where a student designs, constructs and operates a piece of apparatus produces physicists with a broad range of basic skills who can move rapidly in new directions.

Priorities in big and small physics

The decision to construct a major research facility or to embark on a large research program generally requires a consensus within the pertinent research community. Typically this is achieved through debate and discussion conducted by an oversight committee or special panel. The debate may become heated, for different options often appeal to different segments of the community, but if the panel does its work well it will emerge with a prioritized list of the field's needs. These priorities define the major line of scientific development in the years to come, and they provide the funding agency with a reasoned request for the needed support. Time and again this process has helped the fields of big physics to move forward.

The process of setting priorities in small physics is less visible. Because these fields generally advance in many directions simultaneously and change rapidly in response to new opportunities, attempting to forecast the most promising new lines of research is not likely to be productive. Even a cursory look at the advances in the past decade reveals important developments that had not been—and could not have been—anticipated in the early 1970s. Thus priorities in these areas cannot be identified by a short list of topics in order of preference. Furthermore, most of these fields are supported by several agencies, sometimes without much coordination between them. There may be no "champion" agency to push vigorously for the priorities even if they could be succinctly identified.

Nevertheless, the independent research groups do set priorities. The process, though not as formal as in big physics, is just as demanding. The priorities are set by the individual researchers who respond to intellectual challenges as new concepts emerge and new technologies become available, and by their peers, who must give their approval before most agencies will grant funds. Peer review can be a harsh arbiter, particularly when support is short.

Strong evidence for the effectiveness of this priority-setting process can be found by comparing the present "hot topics" with those of ten years ago; the list has changed significantly. The large number of new subfields—some of which were described above—provides a clear picture of how small physics sets its priorities.

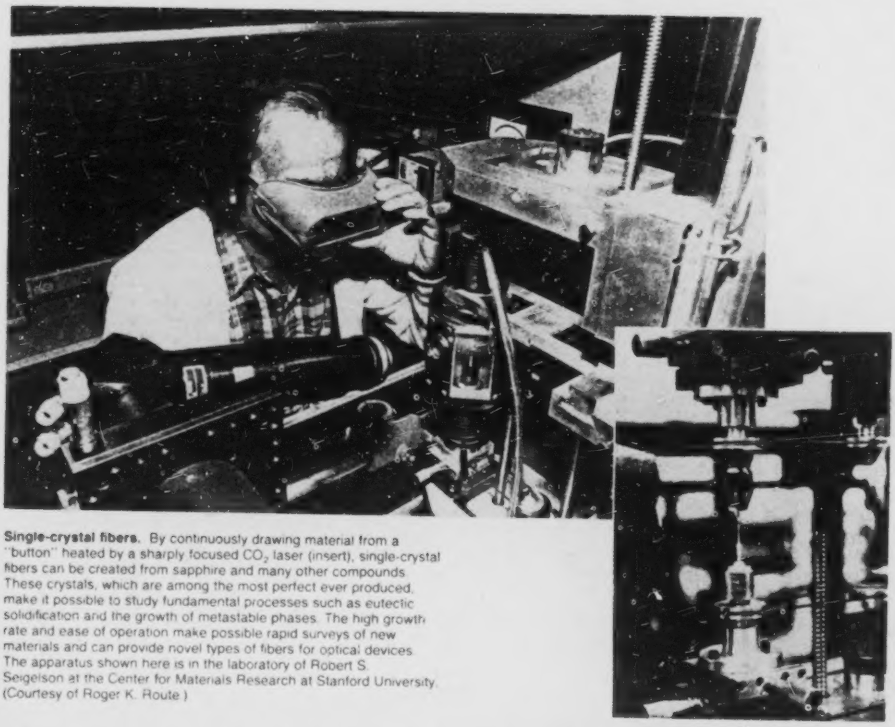
Concerns for the future

In times of cutbacks in the support of science, the small research groups can adapt rapidly to changing conditions. The scope of the research may be diminished and progress may be retarded, but one is not faced with the trauma of closing an existing accelerator or canceling a proposed one. Being small and flexible appears to be an advantage—but it has its dangers. One has an advantage in dealing with short-term cuts in support. However, in a prolonged period of scientific austerity, as we experienced throughout the 1970s, the independent research groups are vulnerable to being slowly starved for support by having to adapt to a pattern of chronic underfunding. The problem of deteriorating support is aggravated by the fact that much of the funding is subjected to the vagaries of mission-oriented agencies, which are neither directly responsible for basic research nor accountable to the basic research community. There is no mechanism for assuring continuity of research when an agency loses interest.

The most conspicuous evidence of serious trouble in small-scale research is the critical shortage of instrumentation in the university laboratories—a problem that has been widely noted.[2] Essential instrumentation in university laboratories is often obsolete or simply missing. The research is being seriously retarded; university groups are being excluded from new research areas. Molecular-beam epitaxy, for example, an important technique for making artificially structured materials, is pursued in many industrial laboratories but in few universities. The $1-million price tag for a molecular-beam epitaxy machine is too high for most research programs.

The DOD–University Instrumentation Program provides a perspective on the problem. In the first year of this five-year program, budgeted at $30 million per year, the requests were over $645 million. Estimates place the total need at over $1 billion.

There are other signs that the climate for small-scale research in the US



Single-crystal fibers. By continuously drawing material from a "button" heated by a sharply focused CO_2 laser (insert), single-crystal fibers can be created from sapphire and many other compounds. These crystals, which are among the most perfect ever produced, make it possible to study fundamental processes such as eutectic solidification and the growth of metastable phases. The high growth rate and ease of operation make possible rapid surveys of new materials and can provide novel types of fibers for optical devices. The apparatus shown here is in the laboratory of Robert S. Seigelson at the Center for Materials Research at Stanford University. (Courtesy of Roger K. Route.)

is deteriorating. Machine shops and electronics shops have been shut down in universities across the nation, and specialized services, such as crystal growing and materials preparation, have been terminated. Forefront research requires a healthy infrastructure of these services; their disappearance is symptomatic of chronic underfunding.

The low number of US graduate students is an additional reason for concern. Although the total of PhDs graduated each year has remained relatively constant for almost a decade, the number of US students has been falling. Forty percent of the entering students are now foreign (see PHYSICS TODAY, September, page 74). The reasons for this are complex. Most US graduate students are supported through grants to the independent research groups, while many foreign students are supported by their home governments. Furthermore, when students see that their professors are unable to purchase vital equipment, to support graduate students, postdocs, visitors and technicians, or even to travel to meetings, they will move to other fields. There can be no doubt that the low funding levels for the independent research groups are a contributing factor to the declining trend in US enrollment.

The picture of postdoctoral employment in the US today is particularly revealing; the *Physics Survey* reports that more than half of the postdoctoral researchers are foreign. These researchers, many of them supported by their own governments, are welcome guests in US research groups that lack funds to support US physicists.

The United States gains much from the foreign students and postdoctoral workers who participate in research here. Furthermore, their training often constitutes a highly cost-effective form of assistance to their countries of origin. Nevertheless, the relatively small number of young US physicists is obviously a source of concern.

There are other underlying problems, though they are harder to quantify. Academic careers involving small-scale research are significantly less attractive today than in the past. Although the number of academic openings is not large, many universities are finding it difficult to fill them with qualified candidates. The universities have lost much of their ability to compete with industrial laboratories. Salary can be an important factor, but the decisive factor is often that the industrial laboratory can provide the resources to move the research ahead rapidly while the university cannot. The demand for academic physicists is expected to increase sharply in the 1990s. Unless the climate for support improves, there will likely be a severe shortage of qualified candidates in universities throughout the nation.

Collectively these problems are cause for deep concern over the future of small-scale research in the United States and the future of physics in our universities.

The cost of small physics

There is wide misconception about the cost of small physics. Even small equipment is expensive. An electron-beam scattering apparatus can cost \$200 000; a tunable laser system, \$150 000—and many experiments use more than one laser. A dilution refrigerator costs \$200 000; a molecular-beam epitaxy machine, as mentioned, can cost $1 million or more. Setting up a typical small laboratory can cost anywhere from a few hundred thousand to over a million dollars; if the research requires services such as materials preparation, the setup costs can be much higher.

Operating an independent research group in a university requires support for graduate students, postdoctoral workers or other research staff, technicians, materials and supplies, and support for the up-to-date equipment. Total costs vary from field to field, but an active university research group can require $200–$400 thousand per year; many groups need much more.

Most of the research support in the US comes from the Federal government. Federal grants supporting experimental research in small groups are generally well under $100 000 per year—far too little to meet the actual costs of the research. Many groups are thus forced to apply for several grants. Physicists spend valuable time searching for support, preparing proposals and juggling budgets between various grants. The time they can spend with students is being diminished; their research is slowed down. This pattern has corrosive effects in laboratories across the nation. Small research groups have lost much of their capacity to pursue new ideas vigorously and to move in new directions.

The large difference between the size of the research grants and the costs of the research threatens the future of the small independent research groups in the US. After a decade of severe winnowing, attempts to direct funding to a smaller number of groups would do as much harm as good. Funding must be brought up to a viable level. Federal concern for basic research within the past few years has provided a favorable climate for addressing these issues. Recent sharp increases in support for some areas of basic physics are encouraging, but the overall situation for the small research groups continues to deteriorate.

A perspective on small physics

The many areas of research in small groups comprise a conglomeration of activities supported by different agencies for different purposes. There is no obvious way to judge the nation's need for any single portion of this research in the context of the total support for physics. It would be difficult, for instance, to attempt to balance the nation's need for low-temperature physics against the nation's need for a new accelerator.

However, if small-group research is viewed collectively, it assumes a clear identity in the world of physics and in the national scene. The small research groups produce much of our best science, and they train the majority of our graduate students; in addition, they generate much of our new technology. Thus these small groups constitute an invaluable resource for the nation.

One can obtain a reasonably clear picture of the national investment in small-scale physics by examining the support for research in the universities. In 1983 the Federal government is estimated[3] to have spent approximately $330 million in the universities for "research and development" in physics. This figure essentially represents support for basic research. Of this amount, approximately $280 million is estimated to be used for research by small groups.

Estimates on the need for support of small physics, based on material gathered by the Physics Survey Committee for its forthcoming report, appear to point to the same conclusion: For the research to move ahead effectively, this support needs to be roughly doubled over a period of perhaps four years. This would require that the nation increase the total investment in these areas by $70 million per year—in real dollars—for four years. In addition, a special infusion of support for instrumentation in university laboratories is needed urgently.

When one views small-scale research collectively and witnesses its enormous impact on science and its abundant returns to society, this research must surely represent one of the most cost-effective ways for the nation to invest in research. The cost of assuring the continued vitality of this research is modest compared to the total cost of modern physics; it is extremely small compared to the national expenditures for research and development based on the fruits of this research.

In the process of deciding the future direction of physics in the United States, the collective needs of the small independent research groups deserve to be considered in parallel with the needs for new accelerators and other major facilities.

• • •

Much of the information in this article is based on material gathered by the Physics Survey Committee of the National Academy of Sciences. The author thanks the members of the Physics Survey Committee, and particularly the chairman, W. F. Brinkman. He also acknowledges helpful discussions with G. B. Benedek, R. J. Birgeneau, A. M. Clogston, C. P. Flynn, W. A. Fowler, T. J. Greytak, G. Holton, V. Jaccarino, M. A. Kastner, J. D. Litster, P. C. Martin, D. E. Pritchard, N. F. Ramsey and D. C. Shapero.

References

1. *Physics Survey*, to be published by NAS–NRC.
2. *Revitalizing Laboratory Instrumentation*, Office of Physical Sciences, NRC, National Academy P., Washington, D.C. (1982).
3. *National Patterns of Science and Technology Resources, 1984*, NSF 84-311, 1984. The estimate of $330 million for 1983 is based on the reported value of $306 million for Federally funded R & D expenditures in physics at universities and colleges in 1982. ☐

Mr. FUQUA. Thank you very much.
Dr. Seitz.

STATEMENT OF DR. FREDERICK SEITZ, PRESIDENT EMERITUS, THE ROCKEFELLER UNIVERSITY, NEW YORK, NY

Dr. SEITZ. Thank you very much, Mr. Chairman.

I had the privilege of being here just a year ago when our Committee on Federal Support for Major Materials was getting underway. At that time, all I could do was describe the plan of the program, give you some idea of how we would carry out our activity.

Actually, we completed the study last summer and emerged with a report on July 24. The committee members are listed on the next to the last page of the document I've provided for the record. As you'll see, it's a very diversified committee. We had individuals strongly interested in large equipment; we had individuals who are essentially benchworkers and work at the smaller scale. We wanted to have a balance. We also had considerable institutional spread.

I had, as my cochairman, a very brilliant young scientist, Dr. Dean Eastman from the International Business Machine Laboratories. We had great cooperation. The report, which I have in my hand, is available through the National Academy of Sciences and may be of interest both to you and to your staffs and will provide much more detail than I will attempt to give here. As a matter of fact, I will give only a summary of the material I've provided for the record.

We focused on equipment that cost at least some sum between $5 and $10 million, and was intended primarily for research in materials across the board in all fields—physics, chemistry, ceramics, electrical engineering, and so forth.

Of continuing concern throughout the committee's deliberations was that there might be a possible misinterpretation of its goals in the report itself. As we emphasized several times, both in the introduction and throughout the report, the knowledge we have from materials research arises from a variety of sources, much from what is called small science; as a matter of fact, most of those individuals who today are interested in the things one can do with the large equipment started their careers working at the bench, on small science, so that the two go hand in hand. As my predecessors commented, one cannot exclude the smaller research. It is, so to speak, the embryonic side of this important field. Different styles are needed.

Nonetheless, our report focuses on the larger equipment, because that was our charge, and I want to make that clear. We looked over the various proposals that were available from the scientific community for large equipment and did our best to prioritize them. We ended up with placing priorities in two general areas. First, new facilities, equipment which is not yet available in any form and which we believe should, in the next decade or more, be constructed and made available, both to an in-house group at the site of the new equipment and to users throughout our country and possibly in other countries.

I want to emphasize that in connection with the new facilities we focused on generic concepts. We did not try to decide the places at which such facilities should be placed.

In addition to that, we were concerned with new capabilities at existing facilities, and we have a list of those, again, in a prioritized manner.

I wish to emphasize that we believe that all of the things that we have recommended, regardless of order, deserve appropriate attention and should be carried out.

The new facilities, in order of priority, are a 6-GeV synchrotron radiation facility; an advanced steady-state neutron facility, which would eventually replace the current facility at Oak Ridge National Laboratory; a synchrotron radiation facility in the range between 1 and 2 GeV, smaller than the one I mentioned first; and the high intensity pulsed neutron facility. There are small pulsed neutron facilities both at Los Alamos Laboratory and at Chicago. The fourth one would be a much larger facility, and we also agreed that a decision on that could be deferred for some period of time while we gain additional information.

The new capabilities at existing facilities, in order of priority, are as follows: Two facilities at existing centers for cold neutron research, incorporating guide halls and instrumentation—again, these would be used not only by the in-house individuals, but by users from other institutions; insertion devices on existing synchrotron radiation facilities—insertion devices enhance the intensities that one can get out of existing facilities, giving strongly focused beams, and we believe that much would be gained by providing funds for insertion devices; an experimental hall and instrumentation facility at the Los Alamos National Laboratory pulsed neutron source—this is a source already in existence; it has been used in the past both for basic research and weapons research. We believe that funds should be made available to expand the capacity of that facility, make it more useful on both frontiers. Then finally, upgrading the National Magnet Laboratory, currently at MIT, a facility which was constructed in the 1960's but which now could be made much more useful.

And finally, enriched pulsed neutron targets, both at Los Alamos for the pulsed facilities, and for the pulsed facilities at Argonne National Laboratory.

You will note that the recommended priorities involve three types of facilities, namely, those for synchrotron radiation, those for neutrons, and those for increased high magnetic fields.

The synchrotron radiation produced when energetic electrons are deflected by a magnetic field, or bent out of course by a magnetic field, provide radiation over a broad spectral range and gives the most intense source of photons now available. Such radiation can be intensified further by orders of magnitude by using insertion devices which concentrate and enhance the radiation, giving coherent radiation. Synchrotron-produced photons interact strongly with atomic electrons and offer a means of probing the details of the electronic structure of materials. It can be used widely in chemistry, physics, and many other fields.

In contrast, neutrons, which are produced by nuclear reactions, interact most strongly with atomic nucleii. Neutrons are thus uniquely suited to the study of lattice dynamics and molecular configurations, particularly useful in studying materials of biological interest which contain hydrogen. Hydrogen does not interact strongly with x rays, but the hydrogen nucleus interacts strongly with neutrons. So it opens up methods of structure determination, for example, for biological materials.

In addition, since the neutron has a magnetic moment, neutron scattering offers a unique means of probing the magnetic properties of materials. The most effective use of cold neutrons, which have very low velocities and are produced by having neutrons from a reactor collide with cold surfaces, requires that they be transported through special tubes in which they are cooled and then, as they lose their velocity, gain longer wavelengths. These arrangements in which the neutrons are cooled are called guide halls, and we believe that they should be made available.

High magnetic fields are essential to the study of a variety of technical and fundamental problems. In particular, high magnetic field facilities are essential to the development of improved superconductors and, in turn, make it possible to construct more efficient superconducting magnets capable of achieving still higher fields.

In the last two pages of the material I will leave, you will find estimated budgets for the various facilities I have just described. You will also find a chart giving proposed ways in which the costs might be distributed over the coming period, say, between now and the end of the century. These are suggested.

I might emphasize, in relation to the budgets, that expressed in terms of current dollars, 1984 and 1985 dollars, these annual expenditures are not out of keeping with what we have done in the past. They are in line, for example, with what we have done for similar facilities over the past 20 years. So we are not asking for any extraordinary change in funding pacing, but for a continuation of what we have done in the past and which has done so much to give our Nation the strength that it has.

I should say, incidentally, that we are now—in the fields I have just mentioned—running into very close competition with our European colleagues. Their facilities, which they do occasionally allow us to use in these same areas, are now overburdened. So it's important that our scientists have access to the things they need.

I think I will terminate my presentation there.

[The prepared statement of Dr. Seitz follows:]

INVITED TESTIMONY BY

Frederick Seitz
Co-Chairman, Major Materials Facilities Committee
to the
House Subcommittee on Energy Development and Applications

Thursday, February 28, 1985
Room 2318, Rayburn House Office Building

Thank you, Mr. Chairman. I am pleased by the opportunity to testify today on the recent report of the National Research Council which sets forth priorities for federal support of major materials research facilities.

My name is Frederick Seitz. I have been a member of the National Academy of Sciences since 1951 and served as its President from 1962 to 1969. Since then I have been at Rockefeller University, serving as President from 1968 to 1978.

Last year, at about this time when you invited me, the National Research Council's Major Materials Facilities Committee had just been formed and I was able to tell you about its charge, plan of action, and then current status. About a year ago the National Academy of Sciences was asked by the Office of Science and Technology Policy to organize a committee to review U.S. needs for Major Materials Facilities, and to establish priorities for the provision of such facilities. Dean E. Eastman and I served as Co-Chairmen of that committee; a list of its members is attached. The Committee completed and delivered its report titled "Major Facilities for Materials Research and Related Disciplines" to OSTP and the sponsoring federal agencies on July 24, 1985. Let me outline for you this morning the conclusions and recommendations of our report.

The report deals solely with major facilities. That was the Committee's charge. The facilities considered were those that are national in scope, with initial costs on the order of $5-10 million or more, intended primarily for research on materials. However, the Committee noted that materials research done on a laboratory scale is equally vital to the future strength of U.S. materials research. Support for laboratory-scale science is complementary to, not competitive with, the support for major facilities recommended.

A continuing concern throughout the Committee's deliberations was the possible misinterpretation of its report. As is emphasized several times the knowledge generated by materials research comes from diverse research styles and performers, each vital to the total effort and each complementary to the other. Those varying styles must each be well supported, for the health of the total effort in materials research. Therefore, the recommendations in the report should be read and interpreted for what they are: a statement as to priorities solely for major materials facilities. The Committee did not address, and the report does not imply, any judgments on the total spectrum of work embraced by materials research.

The report presents priorities both for new facilities and new capabilities at existing facilities with initial cost of at least $5 million. The new facilities in order of priority are: a 6 GeV Synchrotron Radiation Facility; an Advanced Steady State Neutron Facility; a 1 to 2 GeV Synchrotron Radiation Facility; and a High Intensity Pulsed Neutron Facility. The new capabilities at existing facilities in order of priority are: centers for cold neutron research, incorporating guide halls and instrumentation; insertion devices on existing synchrotron radiation facilities; an experimental hall and instrumentation at the Los Alamos National Laboratory Pulsed Neutron Source; upgrading of the National Magnet Laboratory; and enriched pulsed neutron targets.

As noted above, the recommended priorities involve three types of facilities, providing synchrotron radiation, neutrons, and high magnetic fields.

Synchrotron radiation, produced when energetic electrons are deflected by a magnetic field, provides over a broad spectral range the most intense source of photons now available. Such radiation can be intensified further by orders of magnitude by using insertion devices--wigglers and undulators--that put a series of sharp bends in the electron trajectories. Synchrotron-produced photons interact strongly with atomic electrons, thus, offering a means of probing the details of the electronic structure of materials.

In contrast, neutrons, which are produced by nuclear reactions, interact most strongly with atomic nucleii. Neutrons are thus uniquely suited to the study of lattice dynamics and molecular configurations. In addition, since the neutron has a magnetic moment, neutron scattering offers a unique means of probing the magnetic properties of materials. The most effective use cold neutrons, which have very low velocities, requires that they be transported through special tubes, whose walls reflect those neutrons with minimum loss, to large experimental areas called guide halls.

High magnetic fields are essential to the study of a variety of technical and fundamental problems. In particular, high magnetic field facilities are essential to the development of improved superconductors and, in turn, make it possible to construct more efficient superconducting magnets capable of achieving still higher fields.

The Committee's recommended priorities for major facilities--both new facilities and new capabilities at existing ones--embody two prerequisites:

- That they are accompanied by expanded support of smaller materials research programs, including related instrumentation. Research on this scale continues to provide much of the fundamental new science in the field and to train a large fraction of our scientific and technical manpower.
- That resources must be provided to operate existing user facilities productively. In addition, the approved enhancements of major synchrotron radiation facilities at the Brookhaven National Laboratory, Stanford University, and the University of Wisconsin should be completed expeditiously, since it will require several years to more than a decade before the new facilities recommended in this report can contribute to the research effort of the United States.

Priorities for development and construction of facilities during the next decade included two categories:

- Major new facilities, and
- New capabilities at existing facilities.

These categories complement one another in function, time scale, and required resources. New capabilities at existing facilities are essential for scientific and technological needs in the next decade, while the long lead times needed to construct major new synchrotron radiation and neutron facilities require that we start now with the planning and design of such new facilities. They also require that we begin immediately to implement new capabilities at existing facilities. The Committee concluded that both categories are essential for the effective evolution of science and advanced technology in the United States in the next decade and beyond.

The Committee also recommended the convening of additional panels to address other important aspects of materials research.

Let me elaborate on recommendations for the construction of major new facilities in order of priority.

1. A 6 GeV Synchrotron Radiation Facility. This would be designed to make optimum use of the new scientific and technological opportunities presented by insertion devices. These devices, by providing radiation having orders of magnitude greater brightness than currently available, will make it possible to expand on the seminal research using synchrotron radiation carried out in the past decade. A synchrotron radiation facility with a storage ring energy of about 6 GeV will offer both

identifiable and unforseeable new opportunities for research throughout the electromagnetic spectrum. It is optimal for providing radiation from undulators at about 10 keV, where most x-ray research is done. For example, the brightness increase will make it possible to investigate the properties of more complex materials and smaller samples with increased spatial and energy resolution. Site-independent design should begin immediately, and the site selection and construction should commence as soon as possible. If construction were to begin, for example, in FY 87, operation is possible by FY 92.

2. An Advanced Steady State Neutron Facility. The goal is to achieve about ten times the flux of existing machines with a minimum requirement of five times the flux. There are two principal reasons for this recommendation. First, and most important, a high-flux source can be designed to optimize beam geometry and flux distribution, so as to yield greatly increased intensities for all experiments. An increase of about ten times the flux of existing machines is an aggressive but technologically feasible goal. Such a facility would ensure the United States a leading position in this field. This is especially important in the cold neutron range, where flux increases of an order of magnitude can be achieved, providing new capability, for example, for high-resolution spectroscopy and small-angle scattering studies. Second, a new source will be a timely replacement for one or more of our existing sources built in the 1960's. Site-independent design should begin immediately. However, because of safety requirements, the Committee does not expect construction to begin until about FY 89 with completion possibly by FY 96.

3. A 1 to 2 GeV Synchrotron Radiation Facility. This facility would be centered around insertion devices but optimized for the vacuum ultraviolet (VUV) and soft x-ray region. This facility furnishes additional scientific and technical opportunities for research in chemical physics, electron spectroscopy, and imaging techniques such as microscopy and holography.

4. A High-Intensity Pulsed Neutron Facility. Pulsed neutron sources offer new scientific capabilities, especially for investigations requiring higher energy, or greater than thermal, neutrons. Also, there are practical limits to the intensity that steady state reactors can provide. Thus, future improvements in neutron sources, beyond the second priority above, will probably come from alternative approaches, the most promising of which is based on pulsed neutron sources. However, future action on the construction of a high-intensity pulsed source (about 10^{17} neutrons/cm^2-sec peak flux) should be based upon the results obtained with lower-intensity pulsed sources.

Recent developments make it both practical and cost effective to adapt certain existing user facilities to new purposes by adding experimental halls, instruments, and modified sources. These additions provide an opportunity for new frontier science; they are not simply extensions of existing work.

Our recommendations in order of priority for the addition of these new capabilities at existing user facilities are:

1. Centers for Cold Neutron Research. Guide halls and instrumentation for exploiting the only cold neutron sources in the U.S.

located at the Brookhaven National Laboratory and at the National Bureau of Standards, should be developed in an orderly fashion.

There is no cold neutron guide hall in the United States, and such facilities are urgently needed to address the rapid expansion of neutron applications in materials science, chemistry, and biology. Many central problems in these sciences can only be solved using new instruments with cold neutron beams. These centers will enable U.S. scientists to be competitive in cold neutron research during the next decade; and they will provide new instrumentation concepts for developing future neutron scattering sources.

2. Insertion Devices on Existing Synchrotron Radiation Facilities. Insertion devices should be developed in an orderly fashion to exploit about six of the remaining straight sections of existing storage rings. The special characteristics of undulators as radiation sources should be emphasized, to use our existing capability most effectively.

Undulators on existing machines will be our premier synchrotron radiation source for the next 5 years. They will also provide valuable experience for the next generation of synchrotron radiation facilities which will also be based upon undulators. The construction of additional insertion devices, when approved, should follow the construction of new capabilities at synchrotron radiation facilities already included in the budgets for FY 85 and FY 86.

3. Experimental Hall and Instrumentation at the Los Alamos National Laboratory. An experimental hall and new instruments at the pulsed neutron source at the Los Alamos National Laboratory (LANL) would make the

United States competitive in pulsed neutron research and would help guide the development of future pulsed sources.

The expected flux increase at this facility is an important opportunity to explore, at modest cost, the great promise of pulsed neutron science for spectroscopic and structural problems.

4. Upgrading of the National Magnet Laboratory. The need for timely development of pulsed magnetic field facilities and instrumentation enhancements at the National Magnet Laboratory has been demonstrated. This laboratory, the only major high magnetic field research facility in the United States provides a unique combination of high fields and low temperatures. Many advances in research depend on its continued development as a dedicated user facility.

5. Enriched Pulsed Neutron Targets. Enriched targets, by exploiting fission events to amplify the neutron flux, can more than double the available flux. The development and installation of enriched targets for use at pulsed neutron facilities would be cost effective.

Priorities 1 and 2 for major new facilities, when they are implemented, would serve as a centerpiece of this nation's future capability for synchrotron radiation and neutron based research. Thus, design and siting studies for a 6 GeV synchrotron radiation facility and for an advanced steady state neutron facility should begin immediately.

Because of the long lead time associated with an advanced steady state neutron facility, the immediate implementation of at least one instrumented cold neutron guide hall is necessary to provide forefront capability.

Attached are estimated costs and earliest possible schedules for construction and initial instrumentation of the recommended priorities.

MAJOR MATERIALS FACILITIES COMMITTEE

Dean E. Eastman, IBM (Co-Chairman)
Frederick Seitz, Rockefeller University (Co-Chairman)
Richard B. Bernstein, University of California, Los Angeles
Robert J. Birgeneau, Massachusetts Institute of Technology
Jerome B. Cohen, Northwestern University
Mildred S. Dresselhaus, Massachusetts Institute of Technology
Harry G. Drickamer, University of Illinois
Peter Eisenberger, Exxon Research and Engineering Company
Donald M. Engelman, Yale University
Walter Kohn, Institute of Theoretical Physics, Santa Barbara
David W. Lynch, Iowa State University and Ames Laboratory
Albert Narath, AT&T Bell Laboratories
William D. Nix, Stanford University
Edward Rubenstein, Stanford University Medical Center
John J. Rush, National Bureau of Standards
Albert I. Schindler, Naval Research Laboratory
Arthur Sleight, E.I. du Pont de Nemours & Company, Inc.
William P. Slichter, AT&T Bell Laboratories
Joseph V. Smith, University of Chicago
Richard S. Stein, University of Massachusetts
H. Guyford Stever, Universities Research Association
John M. White, University of Texas at Austin

Table III.1 REQUIREMENTS FOR NEW FUNDING*

MAJOR NEW FACILITIES (Millions of FY 85 Dollars)

In order of priority:

1.	6 GeV SR Facility	$ 160
2.	Steady State Neutron Source Facility	260
3.	1 to 2 GeV SR Facility	70
4.	High Intensity Pulsed Neutron Source Facility	330

NEW CAPABILITIES AT EXISTING FACILITIES (Millions of FY 85 Dollars)

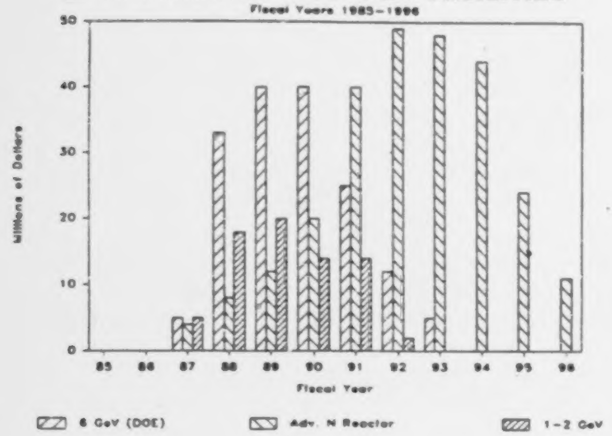
In order of priority:

1.	Centers for Cold Neutron Research	$ 25-35 each
2.	Insertion Devices on Existing SR Facilities	20
3.	Experimental Hall and Instrumentation at LANL	15
4.	National Magnet Laboratory Upgrade	5
5.	Enriched Pulsed Neutron Target	2-5

---

* The Committee's estimates for construction and initial instrumentation costs are largely based on information from facility presentations, program officers, and other knowledgeable colleagues.

A. ESTIMATED COSTS: NEW FACILITIES



B. ESTIMATED COSTS: NEW CAPABILITIES

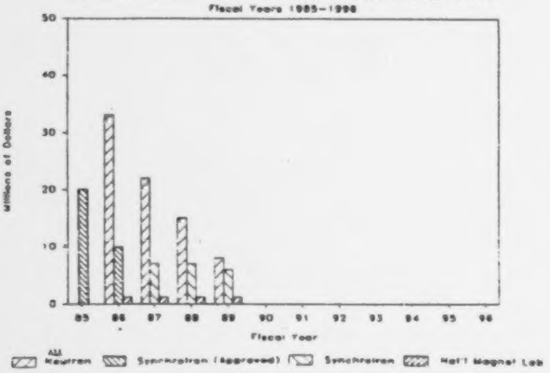


FIGURE III.1. Estimated Costs Versus Year. Estimated costs and earliest possible schedules for construction and initial instrumentation of (a) a 6 GeV synchrotron radiation facility, an advanced steady state neutron source, and a 1-2 GeV synchrotron radiation facility and (b) all recommended priorities for new capabilities at existing facilities.

The funding profile for priority 2 shown in Figure III.1b extends from fiscal years 1987 to 1989. In this schedule, modifications associated with priority 2 would follow the completion of those new capabilities at existing synchrotron facilities that are already included in the budgets for fiscal years 1985 and 1986. The Committee does not necessarily recommend that all priorities be funded at the respective times indicated.

PANEL 1 DISCUSSION

Mr. **Fuqua**. Thank you very much, Dr. Seitz.

Dr. Pimentel, you mentioned in your statement recommendations—and I remember those last year before our committee in chemistry—how has that been reflected, and you touched on it briefly in your statement, how has that been reflected in the fiscal year 1986 budgets for DOE as well as the NSF?

Dr. **Pimentel**. Specifically, I mentioned that DOE has proposed a budget for 1986 that's essentially dollar constant, I think, within a couple hundred thousand dollars. So there has been really no initiative degree of freedom added to the budget, and the same in the Biological Energy Resources Program. All I can say is that I think, under the circumstances of absorbing inflationary changes, we can just expect that that budget will not accommodate new initiatives.

I can't be quantitative about the NSF budget; I haven't studied it in detail, but I do believe that there is some growth in the chemistry area, some very modest growth, but actually above inflation, and I am confident that this is going to be disbursed in accord with recommendations about priority areas that the Advisory Committee for Chemistry is proposing.

Mr. **Fuqua**. What do you see—and I see this has been mentioned in several of them, and it's been of concern to me for some time—as the mix between large science and small science, and particularly in the field of chemistry? The large user facilities, like the National Synchrotron Light Source versus some of the small groups? How do you see that balance? Are we starving the small science, or are they——

Dr. **Pimentel**. I will say that as an absolute statement with reference to small science and chemistry, and I suspect that many of the areas that Dr. Kleppner referred to in physics——

Mr. **Fuqua**. I wanted to ask him the same question regarding physics.

Dr. **Pimentel**. What I would not seem to be saying is that, on a relative scale, that the other groups are being subjected to the same degree of constraint. I just am not aware of that. Certainly I'm aware that the chemistry area, which is of course predominantly a small science area, is struggling with the available resources in view of the very much enhanced cost of the sophisticated instrumentation that can be provided on a shared basis within, let us say, a chemistry department or a local chemistry community, or the dedicated instrumentation—lasers, computers, and the like—that are needed by individual scientists. We're struggling very much. When a proposal is made that one might have another hard x-ray synchrotron light source that might cost $160 million, my immediate response is that that may well be very readily justified in terms of scientific opportunities, but it emphasizes the fact that much smaller amounts will make an enormous impact on chemistry in areas very vital to this country.

Mr. **Fuqua**. Dr. Kleppner, could you give us your thoughts as they relate to physics—the large facilities versus the small?

Dr. **Kleppner**. I feel uncomfortable addressing the issue of large issues versus small facilities because I am a small physicist myself and I really haven't thought that much about all of the rationales for the support for large facilities. I would say, though, that I certainly think that particle physics is one of the most inspiring parts of physics, and that it's an essential part of the physics enterprise.

I would prefer to address the question of the support for small science versus the national need for this science. The national need is enormous. As I indicated, most of the physicists are trained here and most of the new technology comes out of these areas. The national support for small science is very small. When one looks at it collectively, in the universities, the total figure is probably about $350 million in 1984-85. That's a very small fraction of 1 percent of the national R&D effort, and even a smaller fraction if we include the industrial R&D effort; and yet, it is out of this science—not only in physics, but in chemistry and the other basic sciences—that all of this effort has emerged, that we are benefiting right now from past investments, but we are not investing adequately in the future. A tiny fraction of 1 percent is just too small to ensure that the enterprise is going to flourish, and I believe that small physics in our universities is in trouble across the country.

Mr. FUQUA. And how do you see that impacting the training of new scientists, particularly in new science, graduate students, as well as researchers that stay at the universities? Because that, in my opinion, is kind of the feedstock for what the national labs and industry use.

Dr. KLEPPNER. Well, it impacts the training in many ways. One simple way, with respect to the lack of instrumentation, is that we can't train physicists in the universities who can move into the areas which industry is interested in. A good example is in the construction of artificially layered materials by molecular beam epitaxy. It's a terribly important area of science, both scientifically, because of the basic studies, and because of its technological interest. And these areas are being pushed industrially by many large laboratories at a high level, and hardly any university can afford the equipment needed to move into these areas. So we cannot train the students adequately for the Nation's need.

The number of students coming into graduate work in physics has been roughly constant for a number of years now, but in fact the number of American students has been falling. I'm sure you're aware of the figure that 40 percent of our entering students now come from abroad. I think that the lack of U.S. students going into physics represents the perception that one cannot move forward in physics with the vigor and vitality that is needed.

An even more troubling problem is the lack of opportunity for young scientists who want to move into careers in basic science. The difficulties of starting a career in basic physics in the universities now are enormous. A person who is appointed to the faculty and wants to start a research program has a terribly difficult time getting a new proposal simply because the agencies don't have enough money to start these new proposals, and they have a commitment to the ongoing science. This is a very serious barrier, and I think we are seeing the effect already of a decrease of attractiveness for the very best young people into university careers.

I made an informal poll of a number of department chairmen across the country to ask whether they felt there was a shortage of candidates for the positions that they had, even though the number of positions right now is not large. And most of them said yes, they felt this was a serious worry. They were having a hard time attracting scientists into the positions that they had, although formerly these positions would be considered the most desirable place for bright young scientists. When we look into the future, say, 5 years from now, in the early 1990's when the number of positions is going to be very large, there is every reason to believe that there is going to be a critical shortage of scientists and that this will be a terrible problem for the Nation.

Mr. **Fuqua**. Dr. Seitz, would you like to——

Dr. **Seitz**. I think everything that has been said is true. We need continued support, at least to compensate for inflation, both for small science and for large science. They are complementary. You can do things with the big equipment that you couldn't possibly do, so it opens up new horizons, new areas. We need both.

Mr. **Fuqua**. Mr. Packard.

Mr. **Packard**. Thank you, Mr. Chairman.

Dr. Pimentel, you had mentioned—as well as each of the witnesses—the need for new resources; $22 million, I think, was mentioned, which would be a significant increase; and Dr. Kleppner mentioned also the need for new resources.

The notion, I am sure, still persists with some that physicists and chemists and scientists live in their labs and meditate and concentrate and devote their entire lives to their research, and that they are not bothered by the mundane things of where the money comes from, and so forth, that we're here to do that for them. And of course that isn't the truth; you're as vitally concerned about the money resources and the ability to do your work and that of your colleagues as anyone, perhaps more so.

The $22 million is a good example of an increase; that would be a 30-percent increase over existing funding. What can be done—recognizing, again, these constraints that we're faced with, and I'm sure you're not oblivious to those—in terms of genuinely trying to make an effort to balance our judgment in terms of budget constraints and still provide for the very essential needs of ongoing research? Do you have any suggestions for improving? One comment was made that we are reluctant to abandon ongoing projects that may not be at the top of the priority list, that we do not do as well as other countries in doing that. I think that was a comment that you made, Dr. Pimentel. Do you have some concrete suggestions as to improving the system of prioritizing and of evaluating our projects, where we can improve on staying abreast and on the frontier with the money that we have available?

Dr. **Pimentel**. My answer is connected with the agency missions of the various agencies; and as I mentioned earlier this morning, I think it's important to have a more or less continuous reaffirmation of how the scientific leaders in the various agencies see their mission, to present that view of their mission to you and to explain how they feel their existing distribution of resources is responsive to that mission. I suspect that we need to do that somewhat more literally than we have in the past, and I think it's exactly that kind of process which is being faced more directly by the counterpart science policy people in Britain and Sweden and Germany and France and so on, and Japan.

I suspect that by asking annually, perhaps, in hearings like these, the research heads of the various agencies to restate—perhaps identically to last year—but to restate what they see as the fundamental mission of their agency, and to place in that context the various programs, it would give you an opportunity to assess whether indeed you agree with that statement, in which case you can certainly do something about it if you feel that the mission is not well articulated, and you can hear the rationale for the existing distribution of resources among the various possibilities.

Under any circumstances I would add this caveat, that research activities, long-range research activities, thrive only under a fairly continued and sustained support; and if it's necessary to redistribute, it should be done by changing slopes, gradients, and growth and retraction as opposed to large incremental changes, which I think is very cost ineffective and very damaging. But I think that with a clear-cut and repeated reference to the mission of the agency and how the programs support that mission, that you'll have the basis on which to judge whether it's being well done.

Mr. **Packard**. Dr. Kleppner, the universities are having to look outside of Federal funding and local and State funding for much of the research that takes place; and I think they're being pushed, and certainly we're pushing them, in the direction of looking at the private sector as a source for assistance and for funding.

Are you finding that that process is being pursued vigorously by most universities, especially research-oriented universities? And do you have recommendations as to what can be done to enhance that concept?

Dr. **Kleppner**. The process is being pursued vigorously in certain areas. For instance, a classic example is in very large scale integration in electronics, where there are consortia of industries which are supporting an activity at Stanford. We have an activity at Massachusetts Institute of Technology where there's a direct industrial interest in the research. In most areas of basic physics, this does not exist. In condensed matter physics there is a close connection with industry, but that is an exception. There are contributions from industry to the university physics departments—rather, voluntary contributions—for basic support, which are very helpful but only a small part of the total picture.

My own perception is that, with respect to basic physics, we cannot turn to industry and we cannot expect industry to support an appreciable fraction of this enterprise simply because the outcome of basic physics is too unpredictable and too long term, that most industries, I think, could not justify to their stockholders just giving money to a university in the hopes that someday something good to the company will come from that.

Mr. **Packard**. Those comments may have some impact on this last question, and that is, we're finding—I serve on the Public Works Committee, in addition to this one—and I'm aware that in space we're now moving into user kinds of concepts. And in Public Works, of course, we're looking at user fees and have been for some years now as a means of trying to capture additional funding to make the dollars go further.

Are there ways that we can apply the research and development that we find you involved in to this user fee kind of a basis, where those industries that use the technology and profit from the technology could be tapped in terms of resources to promote ongoing research beyond what that technology has presently led us to? Dr. Seitz may be able to——

Dr. **Seitz**. I was president of a research-oriented university for 10 years and got into the heart of all of these problems.

We cannot do it, in any university, without the Federal support or the local support from the State. It's absolutely essential and provides a basis. One can supplement the funds in very important ways by calling upon individuals who have an interest in the research. In the case of the university I headed, which was mainly interested in biomedical activities, there were many private individuals who were anxious to help. Also, private industry would take interest in certain facets and be willing to provide add-ons. But when you examine the picture as a whole it's still true, in the typical American research university today, that the floor for the research program is based on Federal money. The other things are exceedingly important. They provide flexibility; they allow you to get equipment, perhaps, in the short term that you might have to wait a long time for if you try to get it from a science foundation or another agency.

So most universities are working very hard to get a balance, using all resources.

There is one caveat about the industrial support. In a good research-oriented university it's important that that money come in ways which will not so completely distort the interest in basic research that it will prevent the university from carrying out its best function.

I think my objective is obvious in that those who are anxious to see that there are not peaks and valleys in the funding process so that projects can be ongoing, certainly noteworthy projects—and as Federal funds and State funds become either more or less available, it does not force us into those peaks and valleys in terms of the funding process. That's my whole thrust, is seeking for new and different ways of funding and balancing out that whole ongoing funding process.

Mr. **Packard**. Thank you, Mr. Chairman.

Mr. **Fuqua**. Thank you.

Before I call on Mr. Mineta, we're going to double-team you today, all of the witnesses. Those on the third panel and those that precede them, if you care to get some nourishment, Terese will show you where that can happen; and you may, if you want to excuse yourself to do that now, you can meet Terese down here and you'll be back in time—when you come on, because we plan to go straight through.

Mr. Mineta.

Mr. **Mineta**. Thank you very much, Mr. Chairman.

Dr. Kleppner, in your statement you have the research briefing on those six opportunities. Do you have any idea as to what the level of funding would be that would be necessary in order to exploit those six areas of opportunity?

Dr. **Kleppner**. It's a difficult question to answer because all of these areas are areas which will grow with the funding available. It's not a threshold; there isn't a minimum cost for going ahead.

In the area of the laser atomic frontier, certainly an increased funding of about $30 million could be effectively used—not right away, not incremental in that fashion, but over a period of a few years. The other two areas I can't give exact figures for. The disordered materials—that one area is probably comparable in size to the laser atomic frontier, and the biomolecular activity is somewhat smaller.

But I should emphasize that these are selected areas from many other opportunities which would benefit from funding, and that the general need is for increased funding for large areas of basic science. These are a number of opportunities, but just a number from many.

Mr. MINETA. Dr. Seitz, let me ask, in your Seitz-Eastman report—as I understand it—have you ranked the facilities, from your testimony—you have ranked the new facilities for materials research?

Dr. SEITZ. Yes. We believe that all of them should be provided, but we did give a rank order, which is the order that appears in the statements. It is discussed in more detail in this academy report, which is available to you.

Mr. MINETA. As a practical matter, though, I was wondering, could you imagine any circumstance under which the order for construction might be changed without undermining the basic thrust of that report?

Dr. SEITZ. It's conceivable. As I pointed out on the last page of the material I've handed out, we've given a bar chart with a proposed distribution, and it's conceivable that that could be shuffled as far as budgets are concerned.

You'll notice that the focus on the upper chart is on the 6-GeV light source, one of the bar charts. Another is on the nuclear reactor, and the third on the 1-2-GeV light source. As we have presented them here in a suggestive way, they could be interleaved. In any case, the nuclear reactor would be completed, just because of all the regulatory processing that would have to go through, later than the others.

All of these machines would be put to use in highly productive ways.

Mr. MINETA. Dr. Pimentel, as I understand it you are the president-elect of the American Chemical Society?

Dr. PIMENTEL. Yes, sir.

Mr. MINETA. What do you see the role of a society in being able to promote more support for basic research in chemistry?

Dr. PIMENTEL. The American Chemical Society has a rather unique opportunity, I believe, in that regard, and this may well be somewhat relevant to the questions that Mr. Packard has placed. This professional organization has a very substantial membership from industry, and so it does represent an organization that can bring together leading scientists and industry and the universities. That, I think, gives it a nice opportunity to be sure that the industrial and economic opportunities that are coming out of the new frontiers in chemistry are heard and influence the research agenda of the universities, and I think that the ACS furnishes that role. Of course, it takes very detailed interest in the scientific manpower aspect of university education; and, once again, has the opportunity to bring to bear on this question of use of the industries which will be hiring these young chemists.

And then third, there are mechanisms by which the ACS can try to help and support the development of industrial research—pardon me, research support—for university research. The amount of this presently is in the neighborhood of 7 percent or so, and I would certainly endorse all of the remarks that were made by Dr. Seitz about, on the one hand, the very, very great importance of this support because of its possible flexibility; and, on the other hand, the limitations to what you can expect this amount to be, even under the most optimum conditions, if you look to the support as a means of maintaining the kind of professional and academic freedom that characterizes university research and openness—that is, absence of proprietary constraints.

We have estimated that by emphasizing the value to industry—and I'm speaking, of course, of the chemical industry—of the fundamental research in universities as a wellspring of their future personnel, that we might be able to encourage industrial support of fundamental research to be somewhat larger than the present level, of the order of, let us say, 7 or 8 percent. But no one believes that this number could be as large as, let us say, double that amount. And we're actively trying to do what we can to increase it, but we have to come back to the remarks that Dr. Seitz made, that in the last analysis the whole enterprise requires the fundamental base to be provided by Federal support.

Mr. **Mineta**. Thank you very much.

The gentleman from Illinois, Mr. Fawell.

Mr. **Fawell**. I have no questions.

Mr. **Mineta**. Mr. Walgren, the gentleman from Pennsylvania.

Mr. **Walgren**. Thank you, Mr. Chairman.

Dr. Pimentel, I've been told that there is a question about how healthy the basic research in chemistry is, at least in this sense, that many people working in chemistry, a number of people working in really basic chemistry, have to go to the NIH or maybe to the Department of Energy and hook the work that they want to do onto interesting areas of exploration that lie in those jurisdictions, and really are bypassing NSF completely on the grounds that there just isn't enough there or the interest is not there. Are you concerned that basic chemistry investigation is being diverted, or should it be strengthened in its core sense?

Dr. **Pimentel**. That is a question about which I have very strong feelings, and they're all in agreement with sort of the thrust of your question.

But to make this point quantitatively, let me observe that the average grant in chemistry in National Science Foundation will support approximately one postdoctoral student and one and a half graduate students per year, plus supporting costs that go with the kind of research activities that I'm thinking of.

The implication is that for someone who has a very active and productive research program involving, say, 8 to 10 graduate students, which would be common at the major research universities, and possibly 2 or 3 postdoctoral students, that that productive research scientist is devoting a very large amount of attention to trying to gain and maintain 4 or 5 research grants. And that is not cost effective, and the National Science Foundation must have sufficient funds so that it can increase grant size.

Now, it happens that the National Institutes of Health can, in accord with its mission, support organic chemists who are willing to explain their research in terms of the missions of one of the various institutes. And with rather more generous funding, they are able to provide somewhat larger grants; and there's no question that organic chemists in particular, who are the ones who most readily qualify, will tend to go to NIH in preference to the National Science Foundation if they can justify at all. My own feeling is that this may well tend, in some cases, to cause people to do somewhat more straight-forward research projects, somewhat less adventurous and high-risk projects that they might have pursued if they were able to get sufficient funding from the National Science Foundation.

Mr. **Walgren**. Thank you, Mr. Chairman.

I appreciate your response.

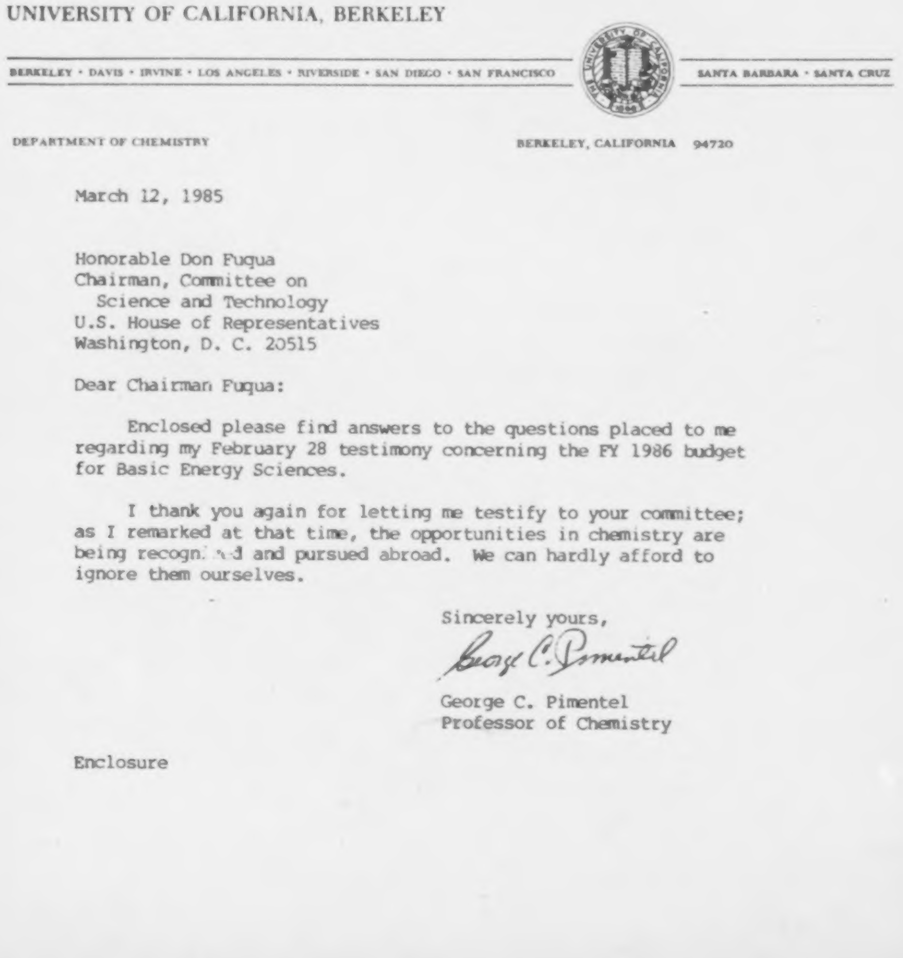
Mr. **Mineta**. The gentleman from Illinois, Mr. Bruce.

Mr. **Bruce**. No questions.

Mr. **Mineta**. Well, Dr. Pimentel, Dr. Seitz, Dr. Kleppner, thank you very, very much for being here at the subcommittee today.

Dr. **Pimentel**. Thank you for letting us come.

[Questions and answers for the record follow:]



UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

DEPARTMENT OF CHEMISTRY BERKELEY, CALIFORNIA 94720

March 12, 1985

Honorable Don Fuqua
Chairman, Committee on
Science and Technology
U.S. House of Representatives
Washington, D. C. 20515

Dear Chairman Fuqua:

Enclosed please find answers to the questions placed to me regarding my February 28 testimony concerning the FY 1986 budget for Basic Energy Sciences.

I thank you again for letting me testify to your committee; as I remarked at that time, the opportunities in chemistry are being recognized and pursued abroad. We can hardly afford to ignore them ourselves.

Sincerely yours,

George C. Pimentel

George C. Pimentel
Professor of Chemistry

Enclosure

Subcommittee on Energy Development and Applications

QUESTIONS

FY 1986 DOE Authorization for Basic Research
February 28, 1985

Dr. Pimentel

1. How are we to take advantage of all these new and exciting research areas you have discussed during a time of such large budget deficits? Are these new research opportunities likely to be more productive than ongoing work? Will the chemistry community be willing to recommend reductions in funding of less productive areas of research so that these new opportunities can be exploited?

In a time of tight budget constraints, it is necessary to pay special attention to those areas of research that, in the longrun, will contribute the most to the DOE mission goals. In view of the importance of continuity in basic research, new initiatives should be examined carefully to be sure that they warrant disruption of existing productive programs.

In fact, the Chemical Sciences program budget is now so tight that the difficult choices are already being made. I cannot speak for the entire chemistry community, but it is my impression that many chemists would view our investment in very large installations (neutron sources, synchrotrons, etc.) as desirable but would be willing to restrain their rate of expansion so that support for smaller projects in the priority areas I have identified could be enhanced. Thus the usage by chemists of the synchrotron at Brookhaven is probably less than 15% of the total time but the Chemical Sciences program supports a much larger percentage of its operating cost, possibly as much as half. The importance of the opportunities in chemistry to the DOE mission makes the cost of the proposed modest increase in this investment to exploit them, $22M, easily justified even if it made necessary a slower advance in these other much more expensive areas.

2. Do you believe that the current DOE Chemical Sciences program has the proper mix of university, DOE Laboratory and industrial research performers?

The present budgetary level in the Chemical Sciences is so constrained that it does not permit contemplation of major realignments without damage to ongoing productive programs. Any increased investment, however, should be divided between National Laboratory and University research performers so as to engage more fully the larger chemistry community outside the National Laboratories. I, personally, do not see a basis for arguing that significant change in the contribution of industrial research performers to the DOE Chemical Sciences program.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
RESEARCH LABORATORY OF ELECTRONICS
CAMBRIDGE MASS 02139

Room 26-231
(617) 253-6811

RECEIVED
[illegible]
COMMITTEE ON SCIENCE
AND TECHNOLOGY

March 14, 1985

The Honorable Don Fuqua
Committee on Science and Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Fuqua,

I very much appreciated the opportunity to appear before the Subcommittee on Energy Development and Applications on February 28, 1985. Herewith are my responses to the questions in your letter of March 5, 1985.

1) Q. How are we to take advantage of all these new and exciting research areas you have discussed during a time of such large budget deficits? Are these new research opportunities likely to be more productive than ongoing work? Will the physics community be willing to recommend reductions in funding of less productive areas of research so that these new opportunities can be exploited?

A. The Research Briefing Panel on Selected Opportunities in Physics was charged "to identify those research areas within the field that are likely to return the highest scientific dividends as a result of incremental federal investment in FY 1986". Because the Briefing was specifically tied to incremental funding, the question of the source of funding, how the funding might impact ongoing research, or whether the research community should cut back in other areas, lies beyond the scope of the Panel's activities. Nevertheless, I am aware of the budgeting problems posed by the deficit. My personal view is this: Fundamentally, the best way to eliminate the deficit is for the nation to grow out of it with an expanding economy. Our continued industrial strength and ability to compete with other nations demands that we develop and exploit new technology. Basic research is the driving force for new technology; the very existence of the present budget deficit makes it more urgent than ever for the United States to maintain a high level of basic research.

As described in my written and oral testimony, the need for support of basic research in physics, particularly in the universities, is urgent. The report of the Research Briefing Panel on Selected Opportunities in Physics offers guidance on opportunities for basic research in several areas which are likely to have a high societal payoff. There are, of course, many other areas for advance. The long term gain from investments in these areas can be expected to be enormous.

2) Q. Could you give us an idea of the level of funding that would be required to exploit the six areas of opportunity covered in the Physics Research Briefing?

A. Research in the topics of the Physics Briefing can respond to incremental funding at practically any level since they involve no major facilities and have no "threshold". The Briefing Panel was not asked to provide budget estimates. However, from informal discussions with members of the Panel I estimate the support which could be used effectively in the three areas described to the Subcommittee as follows:

The Laser-Atomic Frontier. The incremental support needed to support this research most effectively is about $30 million per year.

Deliberately Structured Materials. The support for this area is also estimated to be in the range of $30 million per year.

Biomolecular Dynamics and Intercellular Cooperativity. This enterprise is somewhat smaller than the first two, though it can be expected to grow in the future. At the present time, $10 million/year would have a major impact on its growth.

We do not have at this time estimated budgets for the other three activities - relativistic plasma waves, cosmology and nuclear matter under extreme conditions.

3) Q. Have either the DOE or NSF requested funding of any of these areas of opportunity in their FY 1986 requests?

A. To the best of my knowledge, neither DOE nor NSF has requested special funding for any of these areas in the FY 1986 requests.

4) Q. We sent you a copy of the Committee's Science Policy Task Force's Report, An Agenda for a Study of U.S. Science Policy. Would you like to comment on the Report?

A. The proposed agenda prepared by the Task Force on Science Policy is a coherent and articulate statement of the fundamental issues affecting science in the United States. I was particularly pleased to see the questions on the institutional framework for research, education and manpower, the role of the mission agencies and funding mechanisms. The relevant issues have been identified with exceptional clarity, providing a most useful framework for constructive discussion. The questions posed in the agenda are absolutely vital to the future of science. I am hopeful that the Task Force on Science Policy will succeed in addressing the issues it has so ably identified, and that its findings will play an important role in guiding the evolution of science policy in the United States.

Sincerely,

Daniel Kleppner

Daniel Kleppner
Professor of Physics

THE ROCKEFELLER UNIVERSITY
1230 YORK AVENUE • NEW YORK, NEW YORK 10021-6399

March 12, 1985

The Honorable Don Fuqua
Chairman
Committee on Science and Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Fuqua:

Thank you very much for your letter of March 5th with your complimentary comments concering the Academy report on large scale equipment for materials research. You will find responses to your two questions appended.

Sincerely,

F. Seitz
Frederick Seitz

RECEIVED
12 1985
COMMITTEE ON SCIENCE
AND TECHNOLOGY

Subcommittee on Energy Development and Applications

QUESTIONS
FY 1986 DOE Authorization for Basic Research
February 28, 1985

Dr. Seitz

1. Dr. Seitz, you and Dr. Eastman and the rest of the Committee members are to be congratulated for a job well done on the Major Materials Facilities report. We understand that the Academy is about to begin an even more ambitious study of materials science research priorities. Could you provide us with a brief status report on this proposed activity?

2. We sent you a copy of the Committee's Science Policy Task Force's Report, *An Agenda for a Study of U.S. Science Policy*. Would you like to comment on the Report?

Response to questions

1. It is my understanding that the National Academy of Sciences is seriously considering carrying out and in-depth study of the entire field of material sciences in order to explore the way in which that field interrelates such areas as physics, chemistry, metallurgy, ceramics, electrical engineering,biology and other disciplines. It is my impression that the details of the program have not yet been worked out but are still being considered by an advisory committee to Dr. Frank Press.

2. Regarding the science policy tasks for study, *An Agenda for a Study of U.S. Science Policy*, I was much impressed with the warm interest in the fields of science expressed in the report and am delighted that the Congressional leaders are taking initiative in this matter. As you know, a combination ot events in the 1970's caused us to lose come of the momentum in science our nation had gained in the twenty-five years following World War II. In the meantime, other nations have moved ahead with great vigor and clearly will profit from the advantages they are gaining. I sincerely hope that we will be able to recapture a substantial portion of our leadership in the decade ahead.

PANEL 2: MULTIPROGRAM LABORATORY DIRECTORS

Mr. **Mineta** [acting chairman]. It is a privilege now to call on the second panel, made up of the multi-program laboratory directors: Dr. Alan Schriesheim from Argonne, Dr. David Shirley from LBL, and Dr. Herman Postma from Oak Ridge.

Gentlemen, your full statements will be made a part of the record, so who would like to start off first? Dr. Schriesheim, why don't you go ahead and do that?

[The biographical sketch of Dr. Schriesheim follows:]

Dr. Schriesheim is a research and engineering executive whose experience spans the innovation chain from pioneering sciences to engineering-development and commercialization in both industry and government. He is currently Director of Argonne National Laboratory and professor of Chemistry of the University of Chicago. Prior to this, he was General Manager of the Engineering Technology Department of Exxon Research and Engineering Company. He has held a number of technical management positions at Exxon and was instrumental in building Exxon's Corporate Research Laboratories; he was the director of the Corporate Research Laboratories prior to his position of General Manager. He has also been Vice President of Exxon Research Columbia and a Director of Exxon Engineering Europe. He has a B.S. degree in chemistry from Brooklyn Polytechnical Institute (1951) and a PhD degree in chemistry from the Pennsylvania State University (1954). Schriesheim was affiliated with the National Bureau of Standards before joining Exxon in 1956. He is the author or co-author of over seventy papers, holds 22 U.S. patents and has given numerous lectures covering science, technology, invention and innovation. He was the Karcher Silver Medal Lecturer (U. of Oklahoma, 1977), the 10th Annual Hurd Lecturer (Northwestern, 1980) and the Rosenstiel Award lecturer (Brandeis University, 1982).

He has received the Petroleum Award of the American Chemical Society, is a Fellow of the New York Academy of Sciences and a member of Phi Lambda Upsilon and Sigma Xi (RESA). He is a member of a number of professional societies and has been particularly active in the American Chemical Society where he has been Secretary, Chairman and is currently a Councilor of the Petroleum Division, a member of the Committee on Chemistry and Public Affairs and the Science Policy Committee. He serves or has served on several university/government visiting committees spanning both science and engineering: MIT (chemistry), Princeton (chemistry) (mechanical/aerospace engineering), Stanford (energy), Lehigh (energy research), Argonne National Laboratory (chemistry 1979-1982), University of Chicago (physical sciences) and the National Bureau of Standards where he chaired a subcommittee in the Center for Chemical Engineering (1980-82) and is currently a member of the Central Overview Committee.

He is on the U.S. National Committee to IUPAC and was a member of the IUPAC Subcommittee on Chemistry and Industry (1980-1983). He is Co-Chairman of the National Research Council's Committee on Chemical Sciences and Chairman of an NRC ad hoc panel on chemical research in DOE and a member of the NRC Policy Committee (chaired by George Pimental) which will oversee a report on "Chemistry—Opportunities and Needs". He is also a member of the National Research Council's Energy Engineering Board Committee on Advanced Fossil Energy Technology. He has been appointed to the Science and Engineering Panel of the National Academy of Sciences' Committee on Scholarly Communication with the People's Republic of China. He is a member of the Scientific Policy Board of the Center for Advanced Materials at Lawrence Berkeley Laboratory and is on the Boards of two high tech companies. He is a member of the 1978 Pure and Applied Chemistry Delegation to the People's Republic of China and recently (1981) completed a term on the Petroleum Research Fund Advisory Board. He was a member of the DOE's Energy Research Advisory Board and the materials sub-panel of that Board and the Magnetic Fusion Advisory Committee to the DOE. He has also been elected to membership in the COSMOS Club of Washington, D.C. and the Economics Club of Chicago.

STATEMENT OF DR. ALAN SCHRIESHEIM, DIRECTOR, ARGONNE NATIONAL LABORATORY, ARGONNE, IL

Dr. SCHRIESHEIM. Well, Mr. Chairman, members of the subcommittee, I deeply appreciate the opportunity that you have given me today to describe the programs of Argonne National Laboratory and share with you my extreme concern about the effect of the DOE fiscal year 1986 budget on the programs and, indeed, the very viability of the Laboratory itself.

I have a complete written statement, Mr. Chairman, which, as you have suggested, I have submitted for the record.

I do not plan to read from it today, as there are a few points, simple points, that I consider to be so extraordinarily important that I must make sure that they are covered in the testimony.

I come from an industrial research background; I spent 27 years at Exxon Corp. in various positions of responsibility, with my last position as general manager of engineering. So I feel I am in a particularly advantageous position to comment on the difference between a large corporate industrial research environment where funding predictability is the general rule, and the extraordinarily unstable situation my Laboratory has faced in recent years and which could reach crisis proportions in the year coming up.

Now, put simply, Argonne National Laboratory at its main site in Illinois faces an operating—a cut in its operating budget from $157 million in fiscal year 1985, the DOE operating budget, to $108 million in fiscal year 1986, a cut of almost one-third, not even accounting for inflation. This will mean layoffs of more than one-third of the staff in Illinois, including over 700 scientists and engineers, that would devastate the R&D capability of the Laboratory. The cuts are not directly caused by the Basic Energy Sciences budget. The Basic Energy Sciences budget is flat, so reductions in the Basic Energy Sciences programs will be inflationary only. But the Basic Energy Sciences programs will be hurt.

The supporting infrastructure for these programs that an institution like Argonne provides will be badly eroded. The whole environment in which good research is done will be severely affected by the conditions caused by the layoffs of this order of magnitude.

Now, a laboratory like Argonne, as you well know, is not simply a collection of independent programs. The Lab has the necessary diversity of highly specialized disciplines—chemists, physicists, biologists, engineers—to be able to put whole programs together in the essential way that national laboratories operate. Specialized machine shops, electronics shops, and so on—all the things that are necessary in a world-class R&D institution to allow real advances to be made.

Now, these are not supported by single programs. It is the aggregate of the programs, of diverse funding, that makes the individual programs flourish and makes real research progress possible. It is the institution itself that is important and it is the viability of that institution that is threatened today.

Nevertheless, a lot of exciting things are happening at the Laboratory and I would like to discuss some of them.

Catalysis research, which was mentioned earlier this morning, both by Dr. Trivelpiece and by Dr. Pimentel, is essential to lower cost liquid fuels and industrial chemicals. New experimental techniques and new approaches are certainly paying off. We're converting that Edisonian research in catalysis into a research program within the Nation, certainly within the national laboratories, where we can begin to predict what goes on. A recent discovery, for example, at Argonne involves a new homogeneous catalytic system for the direct conversion of carbon monoxide and water to produce methanol.

High temperature materials—again, a subject touched on earlier—are always keyed to more efficient processes and products. An exciting breakthrough, again at the lab, made possible by high temperature materials, is an Argonne monolithic solid oxide fuel cell, designed to operate at high temperatures, that has twice the power density of diesel or turbine engines.

Tribology is the study of friction and wear—fully 12 percent of the total U.S. energy consumption could be saved by improved tribology of machinery and industrial processes. Argonne is named the lead center for tribology research, and this is the result of extensive surface studies conducted over long periods of time, supported by Basic Energy Sciences.

In biotechnology—plant-based technology, biotechnology—Argonne, in partnership with industry and universities, is developing a new thrust aimed at new crops for biomass production and for chemical feedstocks and for energy conservation and crop production.

I might point out that during the discussion this morning on technology transfer, that Argonne and the University of Chicago have developed, or are in the process of developing, a joint Argonne-University of Chicago Development Center whose function would be to commercialize technology that has been developed within Argonne National Laboratory and at the University of Chicago.

Well, these are a few examples of the exciting programs in Basic Energy Sciences at Argonne today, programs that are exciting to work on, programs that clearly benefit the Nation. As I said, I've provided a complete description of these Basic Energy Sciences programs in my written testimony. But it is the importance of the multidisciplinary nature of the Lab and how interdependent the elements are that, as a laboratory director, I must stress today.

A prime example, and a current one, of both the advantages of the multidisciplinary laboratory, what makes it possible, and the vulnerability it causes if one of the major elements that holds the fabric of the Laboratory together is threatened, is the Laboratory's new integral fast reactor initiative within the Argonne Reactor Development Program. I will not concentrate on this program at all today. Mr. Fawell and Mr. Stallings are very familiar with both the program and the problem; it was covered in detail at another subcommittee hearing last week. However, I would like to say that this integral fast reactor, which shows promise of providing solutions to the major problems facing nuclear power today, was conceived and is being developed at Argonne. Only at Argonne could it be done, because an institution like the Laboratory has the range of specialists that can be brought together as a single unit to make such a concept a reality.

However, the vulnerability is painfully clear. The 1986 budget contains no funds for the integral fast reactor, and sharply cuts the whole Reactor Development Program. The support—this cuts support away from all the other nonreactor programs, and the effect is to engulf the Laboratory in what is literally a battle for its viability, its survival.

It's a grave situation that the budget puts us in today. As a lab director, it is my responsibility to draw this to the attention of the committee, for Basic Energy Sciences is the landlord of the lab. Indeed, it has been responsive, a sorely needed upgrade to aging physical facilities.

In the past few years we have undergone continuous reductions. We have good people; I believe we have good management. We have absorbed the cuts. We have come out to be a strong, healthy, motivated, and innovative laboratory. The cuts we are facing in 1986 are of a totally different magnitude. Over one-third of the staff was subject to layoff on entering the new year. It would be a chaotic situation and one in which it would be hard to predict what would survive.

Well, Mr. Chairman, I appreciate the opportunity you have given me today to comment on the programs of the Laboratory, its status, and to share with you my deep concerns about the future that this budget holds for it. Thank you.

[The prepared statement of Dr. Schriesheim follows:]

PREPARED STATEMENT OF DR. ALAN SCHRIESHEIM, DIRECTOR, ARGONNE NATIONAL LABORATORY

INTRODUCTION

Chairman Fuqua and members of the Subcommittee: I am Alan Schriesheim, Director of Argonne National Laboratory our nation's first national laboratory and one of the world's leading centers of energy research. Our Laboratory is operated by the University of Chicago for the U. S. Department of Energy.

My background in energy research includes over 25 years of research and development management with Exxon. I have also served in an advisory capacity to ERAB, NRC and many universities.

The future development and productivity of our nation is heavily dependent on research of all types: basic and applied, new product development and engineering. Scientific research is the wellspring of new products. It is fundamental to our security and economic stability and vital to our ability to compete in world markets. It is the basis on which America has become a world leader. That leadership is being challenged by others who also understand the value of research. A strong commitment to research is absolutely essential if we are to maintain our leadership role in the world.

As Director of Argonne I am in a position to have an impact on the directions to be taken by government funded research and development. I appreciate the opportunity to describe for you the directions we are taking in the Basic Energy Sciences and to give you a few examples of some exciting research opportunities. In order to most effectively capitalize on these research opportunities Argonne must be viewed as an integrated institution. An institution in which Basic Energy Sciences interact with and reinforce other energy related programs so that the whole is greater than the sum of the individual pieces. I will discuss these programs and interactions during my testimony and also cover the impact of the proposed budget on Argonne National Laboratory.

THE ENERGY RESEARCH OPPORTUNITY

Eleven years after the Oil Embargo, we have found that the elasticity of supply of domestic oil is somewhat less than some had thought, reflecting the high marginal cost of production. Domestic oil prices are up by about a factor of three in real terms while output has hardly changed; proven reserves have fallen.

The failure of domestic oil supplies to increase in the face of higher prices implies greater import dependence, especially if the economy continues to grow. Energy consumption is rising again and oil imports appear poised for another take off. Most projections show steadily rising levels of imports, and potentially higher energy prices. The only way that we can prevent a rise in the prices is by developing technologies that will enable an economical switchover to substitute fuels produced from more abundant resources.

These new technologies may take the form of end-use technologies, for example electric vehicles, or may represent lower cost methods of producing synthetic fuels from shale-oil deposits or from coal. Because the United States is a storehouse of the next generation of fuels, the level and trend of our dependence on energy imports will remain a good indicator of our progress in developing these technologies.

IT IS A MATTER OF COST

Our vulnerability to energy cost increases is most simply and directly illustrated by the synthetic fuels situation. The development of synthetic fuels has long been a central objective of U.S. energy R&D policy. Aimed directly at the need to develop substitutes for depleting conventional oil and gas resources, R&D on these technologies has received substantial private and public support. However, we are still a long way from having economical systems.

The kind of cost barriers encountered in synthetic fuels production is not restricted to these energy forms. With the exception of the advanced fission technologies and the direct combustion of coal for stationary applications, essentially all the new technolgies capable of making a massive contribution to our long run energy supply -- photovoltaics, fusion energy, geothermal gas, electric batteries and fuel cells for vehicle application, and biomass energy -- are substantially more expensive than the conventional technologies they would replace. At the same time, none of the advanced technologies is pressing against theoretical performance limits, and each holds promise for further cost reduction through research and development. I believe the grace period before the inevitable run up in energy prices will be best spent on a "back to the basics" approach to energy research. This approach, of course, carries with it increasing responsibility for, and expectations of, Basic Energy Sciences.

SOME EXAMPLES

Rather than try to cover the spectrum of the Basic Energy Sciences, I shall limit my remarks to a few areas. My purpose is to illustrate the kinds of Basic Energy Sciences research programs that offer promise for a secure energy future and that contribute to the scientific leading edge which we all agree is so important to our competitive standing in the modern world.

On this latter point I take great pride in noting that last year at Argonne, five of our scientists were selected by their peers as being among the 100 best young scientists in the country.

CATALYSIS RESEARCH

Catalysis research is an example of a generic research area that can lead to dramatic improvements in the performance of advanced energy technologies, and one of primary importance in Basic Energy Sciences. Catalysis will play a central role in our efforts to develop lower-cost sources of liquid fuels and more efficient processes for producing industrial chemicals.

There are a number of scientific approaches toward a better understanding of catalytic mechanisms, including the chemistry of organometallic complexes and metal cluster compounds, structural modifications of catalytic support, and chemical synthesis. New experimental techniques hold the promise of deepening our understanding of the basic mechanisms and of paving the way to a theoretical, rather than a phenomenological approach to catalysis. For example, studies of a critically important class of catalysts called zeolites are being conducted at the Argonne Intense Pulsed Neutron Source by a number of industries including Exxon, Amoco and Schlumberger.

HIGH-TEMPERATURE MATERIALS

Another area of importance to the nation is materials. Materials performance, especially at high temperatures, is recognized as the principal barrier to the development of more efficient and reliable energy technologies. Materials advances are almost always the key to development of more efficient and reliable processes and products. Improved alloys and ceramics are currently finding their way into a wide variety of high-temperature, energy-saving applications, including structural ceramics for recuperators and engine components, and composite materials for high-strength applications. For the future we see excellent potential for materials developments such as wider classes of transformation-toughened ceramics, electrically-conducting ceramics, new alloys tailored for corrosion/erosion resistance and high-temperature applications, and a whole array of new coatings technologies for improved friction and wear resistance. In all of these areas, innovative Basic Energy Sciences programs in materials sciences are leading the way.

An example of the breakthroughs possible with advanced high temperature materials is provided by the monolithic solid oxide fuel cell developed at Argonne. This advance was made possible by the underlying materials research effort sponsored over the years by Basic Energy Sciences. Funded by DARPA, the program is working toward a ceramic fuel cell power supply, operating at 1000°C on a variety of fuels, that has more than twice the power and energy density of diesel or turbine engines. In order to achieve this, improvements in the fabricability of multi-layered, multi-component ceramics only a few mils thick, along with advances in thermal and chemical stability are required. Clever design is, of course, also necessary, but the development of this technology is clearly paced by our ability to design and fabricate the ceramic components. I am happy to report that the Argonne team has just achieved the major milestone of producing power from the first laboratory test cell. Much work remains to achieve the design goals, of course; arrays of these cells must be fabricated and manifolded, and many difficult steps remain. Nevertheless, it is an example of the potential that can be unlocked with improvements in high-temperature materials.

TRIBOLOGY RESEARCH (THE SCIENCE OF FRICTION, WEAR, CORROSION AND LUBRICATION)

Recent studies have shown that approximately 12% of the total U.S. energy consumption per year, or approximately 20-billion dollars per year, can potentially be saved by the improved tribological performance of machinery and industrial processes. Recently it has been realized that the development of certain new high technology areas such as the development of an adiabatic diesel engine, of high speed and high temperature gas turbines, and high speed materials processing at elevated temperatures cannot be accomplished without major breakthroughs in tribology. The solutions to tribological problems typically require the collaboration of scientists and engineers of various disciplines, such as materials sciences, physics, chemistry and mechanical engineering. The Department of Energy has designated ANL as its lead center for tribology research and assigned us responsibility for management of the National Tribology R&D program. This was due in large measure to our outstanding record of research accomplishments in the basic surface sciences - work funded through Basic Energy Sciences programs, and our extensive experience in operating user facilities for industry, universities, and other scientific organizations.

A major goal of the center is to develop novel solid lubricants and wear surfaces to operate under the adverse conditions of high temperature and erosive and corrosive environments. We will establish close ties with U.S. industry to determine current and future needs and to facilitate the transfer of the new technology.

NEW INITIATIVES/OPPORTUNITIES

I would like to continue this discussion by describing several new Argonne initiatives and some potential opportunities that could be missed if we fail to act.

ADVANCED COMPUTING

Computers are becoming powerful enough to make possible for the first time the analysis of complex scientific and engineering problems that have defied analytical and experimental techniques. Many real-world constraints such as time, instrumentation, and environmental impacts can be avoided with large-scale computer simulations. Computational science seems ready to take its place as the third scientific methodology, alongside theory and experimentation. New machines yield unprecedented performance while high performance automated reasoning techniques open up new application areas. These developments result from advances in computer architectures and non-numerical techniques. Far from leading to a steady state, these advances spur demands for increased performance that can only be achieved through the use of extensive parallelism in computer architectures. The complexity of the resulting systems poses formidable challenges. We must not only find ways to organize and express computations so that high performance is obtained on new architectures, but also discover how to avoid repeating the process for each new design.

Little support has been given to research that addresses these issues. Among the projects that Argonne has proposed are: a) research on portable yet high-performance algorithms and software, especially for automated reasoning, logic programming, and numerical tasks; b) creation of programming tools and environments that promote efficient and portable programming for advanced computers; even the fastest hardware is of little use if programming environments are inadequate; and c) development of methodologies for assessing advanced architectures that enable reliable prediction and measurement of their performance for given applications.

A network of Advanced Computing Research Facilities is essential for this research. The issues to be studied are complex and intertwined; portability and efficacy of software can ultimately only be validated by experiments on prototype advanced machines. Additional funds for Basic Energy Sciences are needed to translate the many exciting ideas into reality.

BIOTECHNOLOGY

Next is a program in the general area of biotechnology but specifically related to basic research in plant based biotechnology. This thrust will involve the DOE, universities, Argonne, and industry. This program will aim at new advances in biotechnology as applied to the conservation of energy in crop production, to developing new crops for biomass production, or crops as sources of chemical feedstocks. Within the next year, we will be acquiring staff for joint efforts with two universities in these fields and holding a major colloquim in this research area, which will be supported by industry, Argonne, participating universities, and DOE. We expect that this meeting will delineate perceived needs for commercialization, the state-of-the-technical-art as it applies to such needs, and directions for future research.

ADVANCED SYNCHROTRON RADIATION SOURCE

ANL is taking a leading role in a project that has attractive wide support in the material science community. This is a high energy synchrotron radiation source.

Over the last decade, synchrotron radiation has become an analytical tool of particular importance in materials science and atomic physics. Now, with advances in accelerator concepts and technology together with the development of so-called insertion devices, we stand at a threshold; a new generation of synchrotron radiation sources is capable of providing unprecedentedly brilliant radiation, with striking opportunities for science and technology. For example, the atomic structures of tiny crystals can be obtained, a capability geologists and catalytic scientists have long sought; the microstructure of important structural alloys, both old and new, can be determined with high precision, leading to materials of superior performance; chemists and biologists will be able to "watch" fast chemical reactions as they occur, thus elucidating elusive intermediate reaction steps and thereby providing the knowledge to control important functions and processes; and new lithographic techniques will permit the fabrication of even more compact microcircuits and higher density computer chips with remarkable precision.

Our ability to construct accelerators is demonstrated by the upcoming startup of ATLAS, a nuclear physics project. This facility will come in on budget and on schedule.

It should be noted here that this system, built with funds from the High Energy and Nuclear Physics programs, could not have been built without the understanding of superconductivity and superconducting materials to which the Basic Energy Sciences programs have contributed so much. In fact, niobium accelerator elements are being fabricated at Argonne for use at Florida State University and Kansas State University.

ARGONNE/UNIVERSITY OF CHICAGO DEVELOPMENT CORPORATION

Before leaving this area of research accomplishments and new initiatives, I will touch briefly on a new thrust geared to commercialize technology developed at Argonne and its contractor the University of Chicago.

We constantly are searching for ways to improve our nation's competitive posture and to increase productivity through transfer of the knowledge gained from our research. To this end we are forming a joint Argonne/University of Chicago Development Corporation which will encourage and aid the development of intellectual property developed at ANL and the University of Chicago. The Corporation will commercialize new technologies by licensing patents for royalties and developing privately-funded, joint ventures for capitalization. The Corporation will be separate from ANL and ANL's contractor (The University of Chicago), with overview by a board of directors. A search for appropriate leadership and staff is presently underway. A portfolio of patents and other intellectual properties has been prepared for evaluation and use by the Corporation, which is expected to approach self-sufficient status after three years of operation.

PHYSICAL FACILITIES

Talented research people must be supported by state-of-the-art facilities for optimal program performance. I need to comment on the physical facilities of the national laboratories. These have been allowed to deteriorate in past years through lack of support. The Department of Energy has recognized this problem and facilities support has been increased significantly in recent years through the Multiprogram General Purpose Facility (MGPF) program which was established in 1981 to respond to this deterioration. ANL funding from this program along with the General Plant Project (GPP) program has steadily increased from $4.4 million in FY 1981 to $13.6 million in FY 1985. Even with these improved funding levels, the age-related deterioration of the facilities at all the Multiprogram Laboratories still exceeds rehabilitation funding. Acknowledging this, the Department of Energy has directed the Multiprogram Laboratories to develop an accelerated facilities revitalization program, beginning in FY 1987. This program is designed to halt any further deterioration of the physical facilities. If implemented, it will restore the facilities to a level consistent with the high quality scientific work being performed at the Laboratory.

WILL THERE BE MISSED OPPORTUNITIES?

The examples discussed above have evolved from the on-going programs in the Laboratory -- many funded by Basic Energy Sciences over the years. However, to take maximum advantage of the many opportunities, the whole institution must be healthy. Adequate funding involves not only a reasonable level to support a balanced program, but also funding which is predictable and consistent from year to year. There are few actions more debilitating to an effective research program than large fluctuations in funding.

I must report to you today that my Laboratory is threatened next year with the loss of more than 20% of its present operating budget. The major direct impact of this reduction is not in our Basic Energy Sciences budget. In fact, the Basic Energy Sciences budget is flat which results in a slight reduction due to inflation.

The greatest impact will be felt in the other parts of our Laboratory, those supported by the Nuclear Energy Program and other programs within the Department of Energy. The changes would virtually eliminate the best comprehensive advanced reactor research and development capability left in the nation.

The important point is that a laboratory is not a collection of independent programs. A laboratory first and foremost is an institution with many interrelated efforts. Loss of major support in one area impacts other parts of the institution. We must focus on the importance of the multidisciplinary character of a balanced research organization to maintain its well-being and stability. Without this focus even those programs whose support is maintained will suffer.

Mr. MINETA. Thank you very much, Dr. Schriesheim.

Dr. Shirley. Go ahead, proceed.

STATEMENT OF DR. DAVID A. SHIRLEY, DIRECTOR, LAWRENCE BERKELEY LABORATORY, BERKELEY, CA

Dr. SHIRLEY. Mr. Chairman, and members of the subcommittee, in your letter inviting me to testify today you requested that I address three topics: The Department of Energy's Basic Energy Sciences Program, the effect on the Lawrence Berkeley Laboratory of reductions in the Department's fiscal year 1986 budget request, and the agenda to be considered in the Science and Tehnology Committee's coming review of science policy. I'd like to connect these three topics through the single theme of national need.

Future science policy should, in my view, above all, ensure that federally funded science serves our most important national needs. The Basic Energy Sciences Program indeed serves a very critical set of national needs. In accord with this theme, the Lawrence Berkeley Laboratory is being redirected to place greater emphasis on the Basic Energy Sciences because we perceive these needs as being of paramount importance to the Nation's energy program in the years ahead.

LBL is a multiprogram national laboratory operated under contract by the University of California for the Department of Energy. We employ roughly 4,000 people, including a large number of graduate students and faculty members. Our total budgets for fiscal years 1984 and 1985 and 1986 are $169 million, $175 million, and $169 million, respectively. The DOE operating budget for those 3 years decreases monotonically from $115 million to $111 million to $105 million in fiscal 1986, according to the budget request. On top of inflation, the 1986 budget will mean devastating reductions in LBL personnel and scientific programs; in fact, if you calculate our real resources from the DOE operating budget and correct for inflation, you get a decline of up to 24 percent in real resources in 2 years.

The Basic Energy Sciences Program is slated for a reduction of $12.8 million in the fiscal year 1986 budget. This proposed reduction is a major concern to our Laboratory as the Laboratory continues its transition to a multiprogram laboratory whose future direction is increasingly tied to the Basic Energy Sciences.

In the last few years there have been numerous reviews of the roles and missions of our national laboratories. These studies have been very useful to us, and we are very clear on our mission, our goal, and our strategy for achieving that goal. Our goal is to become a stable, premier, multidisciplinary national laboratory by 1990, but our ability to achieve this goal will be seriously diminished by the 1986 budget.

Our mission is threefold. Our primary mission is to perform outstanding basic research in general sciences and energy sciences. In general sciences, our strategy is to stabilize our high energy and nuclear physics programs. The choice of LBL as the host of the Superconducting Super Collider Central Design Group reflects our relative success in this area. I'll return in a moment for the strategy in energy sciences.

The second component of our mission has to do with LBL's unique relationship with the University of California and our proximity to its Berkeley Campus. This has allowed us to successfully carry out a major education mission. Over 700 graduate students are earning their advanced degrees while participating in LBL research programs onsite. More than any other institution in this country, LBL contributes new scientists to the energy sciences.

Budget reductions will mean a major drop in the number of students at LBL. With our Nation's technical supremacy being challenged from abroad, and one study after another urging a better scientific education for our youth, this short-term budgetary decision will result in long-term damage to our scientific and technological future.

The third part of our mission is the development and the operation of major national experimental facilities. This mission is, we believe, central to the operation of national laboratories. Our major facility, the Bevalac, is now 30 years old, and we are thinking of new facilities. And again, I will return to that.

Our reorientation to a BES-based laboratory is well on its way. We are building on strength and distinction. LBL can claim some 35 members of the prestigious National Academy of Sciences and National Academy of Engineering, and 27 of those 35 work in Basic Energy Sciences-supported areas. Even more important, LBL has some 6 of the 100 brightest young scientists in the United States, as reported recently by Science Digest. And they are supported totally or in part, every one of them, by Basic Energy Sciences funds.

Let me give you some examples of the new initiatives that we have undertaken in the Basic Energy Sciences, even in the light of our recent constrained budget. LBL, in conjunction with Exxon, led the design and construction of the world's brightest x-ray source at the Stanford Synchrotron Radiation Laboratory. Another example, our National Center for Electron Microscopy, which opened in fiscal year 1983, is now providing unique materials characterization facilities for materials scientists, surface scientists, and biologists, including atomic resolution microscopy.

Our major new initiative is the Center for Advanced Materials. With the support of the Materials Science Program in Basic Energy Sciences and the Congress, the Center for Advanced Materials began operation in fiscal year 1984. Its programs in catalysis, polymers, ceramics, electronic materials, and innovative instrumentation have been designed with guidance from American industry. Each program undergoes review by an industrial advisory panel, and several industrial laboratories have sent their scientists for extended tours of duty at CAM, the Center for Advanced Materials.

In 17 months, the scientific progress has been impressive. The next step is to provide CAM a modern home with up-to-date equipment that is conducive to more effective collaboration and collaboration among our own staff. We are presently using rather antiquated facilities.

The fiscal year 1986 budget request for CAM construction will enable us to move toward this goal.

Now I come to the major element in our strategy. An important step in strengthening our capabilities in synchrotron radiation was to establish the Center for X-ray Optics. Along with our accelerator designers, this group is the nucleus for a future LBL role as operator of a next generation synchrotron light source. We are pleased that the National Academy of Sciences' Major Facilities for Research Panel, whose report you just heard, recognizes the vital need for new materials research facilities. We believe that LBL would be an ideal location for the soft x-ray source that has been recommended.

All of these new initiatives were started despite uncertain budgetary conditions and were supported by BES funds. The scientific vitality and creativity of a national laboratory depends on encouraging new initiatives whenever they emerge. Reduced or steady State funding levels for Basic Energy Sciences programs threatens these new initiatives.

Adjusting to budget reductions is nothing new for LBL. As you know, in 1981, in 1982, there was a serious retrenchment of the national laboratories, the Energy Sciences-related national laboratories, including LBL. We were forced to reduce our work force by almost 600 people, or some 19 percent of our total work force. In the next 2 years, however, in 1983 and 1984, those years were rebuilding years at LBL. This rebuilding was possible because of a commitment by the administration and the Congress to strong Federal support of basic research.

The proposed 1986 LBL budget would mean a reduction of 300 people from our work force, and would require major cuts in scientific programs at the Laboratory.

I'd like to comment on the impact that this would have on user facilities specifically. I'll comment on three user facilities, of a much larger number which we have at LBL.

The availability of the National Center for Electron Microscopy, which is only about a year old—its availability to users—will be reduced.

The reductions in the fusion program may force the shutdown of the Neutral Beam Engineering Test Facility, and will mean major cuts in our associated research programs.

However, I'd like to emphasize the impact on the operation of the Bevalac. The operation of the Bevalac would be cut back to 7.5 months, approximately, compared to an optimal level of 9 or 10 months, which is a level that we achieved in 1984, thanks to a review of the operating budget for the Bevalac. Unfortunately, the operating budget is then constant from 1984 to 1985 to 1986, and does not have augmentation for inflation. This would not only adversely affect nuclear science research and student education, but would also have a serious impact on the cancer therapy program which demands a measure of continuity in its treatment protocols. And I must say, I really hate to see that program damaged.

It may come as a surprise that major reductions are occurring at LBL while the overall Research and Development budget continues to rise. For 1986, overall R&D spending, Federal spending, is slated to rise some 2 percent over 1985, but the figures look different when broken down by agency and mission. R&D funding at the Department of Defense is budgeted to rise some 22 percent, and funding for the National Science Foundation, 7 percent. DOE funding of R&D, however, is scheduled to drop approximately 2 percent, and when the increase in military R&D is subtracted, basic research actually drops by our count by approximately 8 percent.

This is particularly damaging to the national laboratories because, unlike research programs that are funded on a project grant basis, we are not able to spread out the damage over the coming years; but rather, we must make reductions in our work force by approximately July 1 in order to go into the coming year in a fiscally sound position.

Our national laboratories are a long-term investment in our Nation. Their scientific health will have a major impact on the ability of American industry to remain technologically competitive. A stable research environment is vitally important to their productivity. Without this commitment there will be a significant deterioration in the quality of scientific research. Scientists will look for more stable environments in which they can perform their research. Recruitment of new scientists and engineers will become more difficult, and students may rethink their commitment to fields in which their professional future would always be in question.

I'd like to thank the subcommittee for inviting us here today. The importance of basic research to the future of our Nation cannot be overstated. I hope that today's deliberations will contribute to educating your colleagues and mine about the importance of Federal funding for basic scientific research.

Thank you.

[The prepared statement of Dr. Shirley follows:]

FINAL

Testimony of Dr. David A. Shirley
Director
Lawrence Berkeley Laboratory
Before the
Energy Development and Applications Subcommittee
of the
House Science and Technology Committee
Thursday, February 28, 1985

Mr. Chairman and Members of the Subcommittee:

In your letter inviting me to testify today, you requested that I address the Department of Energy's Basic Energy Science programs, the effect on the Lawrence Berkeley Laboratory (LBL) of reductions in the Department's FY 1986 budget, and the agenda to be addressed by the Science Committee's review of science policy.

The importance of the Basic Energy Sciences programs to our nation and to LBL as an institution cannot be overstated. Despite the current oil and gas glut and softened energy prices for the U.S., no one expects this to last. In fact, because of the strong dollar, our international allies, who are also our economic competitors, face increasing energy prices and strong incentives to continue basic research and development for new energy supply and utilization technologies.

New and better materials mean better nuclear reactors, more efficient turbines, and more efficient and cost-effective ways to make steel and glass. To stretch out our conventional supplies of oil and gas, better, more innovative, more efficient refining processes require better understanding of fundamental chemical interactions of hydrocarbons. Basic chemistry underlies new technologies to harness biomass and convert coal and oil shale into more convenient, cleaner fuels. Fundamental understanding in the geosciences is required to improve our control of nuclear waste disposal, enhanced oil and gas recovery, and geothermal resources, as well as the dispersal of undesirable effluents and emissions from energy technologies.

In these areas and others supported by BES programs, DOE has a unique role to play. Within that role, DOE's national laboratories and LBL in particular can make special contributions.

At this point, I would like to tell you about

- The Lawrence Berkeley Laboratory and its mission;
- How its DOE funding has produced results for the nation;
- How our BES funding is helping to provide a new direction of excellence for one DOE national laboratory that combines its historical strengths with those of industry and a major research university.

LBL is a multiprogram national laboratory operated under contract by the University of California for the Department of Energy. We employ roughly 4000 people, but because of our large number of graduate students, faculty members and visiting scientists, we only have about 2700 full-time equivalent (FTE) positions. For fiscal year 1985, LBL's total budget is just under $175 million, of which $29 million is construction and capital equipment. This compares to fiscal year 1984's budget of about $169 million, which included $22 million in construction and capital equipment. The FY 1985 budget represents a decrease in LBL's DOE operating funds of almost $3 million, or about 10% with LBL's inflation factor, when compared to FY 1984. The FY 1986 budget will mean even more dramatic reductions in LBL personnel and scientific programs, and will have serious consequences for the ongoing performance of one of our nation's premier basic research laboratories.

The Basic Energy Sciences program is slated for a reduction of $12.8 million, or 7.3% with inflation, in the FY 1986 budget. This proposed reduction is a major concern to LBL as our laboratory continues its transition from a single-purpose, high-energy physics laboratory to a multiprogram laboratory whose future direction is increasingly tied to the Basic Energy Sciences programs as well a other programs in the Office of Energy Research.

LBL's Mission

In the last few years, there have been numerous reviews of the roles and missions of our national laboratories, and these have been useful in clarifying and strengthening the roles and mission of LBL. Our mission today is threefold: we perform multidisciplinary research in general science and energy sciences, we develop and operate major national experimental facilities for use by qualified investigators, and we provide educational and training opportunities to the next generation of scientists and engineers. In each of these areas, LBL's historical strengths provide the base for us to move the laboratory forward to a strong and secure future. Our goal is for LBL to become a premier multidisciplinary national laboratory by 1990. But our ability to implement these missions and achieve our goal will be seriously diminished by the 1986 budget especially if it becomes a trend for the DOE basic research programs.

The primary aspect of LBL's mission is to perform multidisciplinary research in general science and energy sciences. The research we have performed, and our research plans for the coming years, will make a major contribution to our country's basic research efforts.

LBL's unique relationship with the University of California, and especially our proximity to its Berkeley campus, has provided us with the opportunity to carry out our educational mission more successfully than any other national laboratory. In fact, our location next to what may be the world's preeminent research university impells much of our research, and the combined forces of LBL and UCB make for a highly productive national laboratory that, because of the university's involvement, is an outstanding bargain for the federal government. We currently have over 700 graduate students earning their advanced degrees while participating in research projects under the direction of LBL scientists and engineers. These students are the scientists and engineers of tomorrow who will make major contributions to our universities, corporations and national laboratories. Budget reductions, unfortunately, will mean a significant reduction in the number of students that LBL can accommodate, since there will be fewer research programs and LBL personnel with whom they can be associated. This means a reduction in the number of future scientists and engineers trained and educated at LBL and UC Berkeley, and considering the overall budgetary situation, it is unlikely that this reduction can be made up by other national laboratories or universities. At a time when our nation's technical supremacy is being seriously challenged from abroad, and one prestigious study after another urges a better scientific education for our nation's youth, this short-term budgetary decision will result in long-term damage to our nation's scientific and technological future.

The third component of our mission is the development and operation of major national experimental facilities for use by qualified investigators. This mission is central, not only to LBL but to national laboratories in general, for it is national laboratories, because of their size and multidisciplinary nature, which are better equipped to handle the efficient development and operation of these facilities. From the first days of the Bevalac's operation, LBL has played a leading role in this area, and today we are working on a number of new and potentially exciting user facilities.

A New Focus for the Laboratory: History and Future Plans

LBL's beginnings on the UC Berkeley campus in 1931 were as a high-energy physics laboratory, and many fundamental physics discoveries of the 1940's, 50's and 60's were made at LBL. As high-energy physicists continue to expand the frontiers of their research, the facilities required to carry out this research have become too large to locate at LBL. Since 1970, we have continued our preeminent work in high-energy physics by designing new innovative particle detectors and contributing to discoveries at these large facilities. Our work in this area continues to be of the highest caliber, as illustrated by the choice of LBL to host the Central Design Group for the Superconducting Super Collider, the next generation high-energy physics accelerator. A major component of our strategy for the future is to stabilize our high-energy and nuclear physics programs, building on their historical strengths and their promising future.

As the 1970's unfolded, LBL continued to develop its materials and chemistry programs, whose capabilities were originally developed to support the high energy physics program and the civilian nuclear reactor program. With the energy crisis of 1973 came new and important activities to develop technologies for energy efficiency in buildings and lighting and renewable energy resources. Our Bevalac accelerator became a national user facility which is now providing heavy-ion beams for the nuclear physics program. Our Biology and Medicine Division has been using the dose localization properties of heavy-ion beams from our accelerators for experimental treatment of cancer and other localized diseases. For some conditions, heavy ions are now the treatment of choice.

As we entered the 1980's, LBL faced several challenges. As a unique user facility, the Bevalac is offering tantalizing hints of a new understanding of nuclear matter. Its on-going efforts, with higher resolution and versatile detectors, may provide an exciting view of nuclear matter under extreme conditions. Now thirty years old, the Bevalac's relativistic heavy-ion beams are showing the way to the next generation of machines for this exciting field. But future machines will be of significantly higher energy and possibly too big to be located on the LBL site. With this, and the other changes mentioned, we have had to take a serious look at where we want to be and what kind of research facilities and programs LBL should undertake for DOE and the scientific community.

At the same time that LBL was beginning its transition period to a multiprogram laboratory, DOE and the Congress recognized the need to provide increased support for materials and chemistry research to develop new energy technologies, provide trained manpower for the energy industries, and to lay the groundwork for technological innovation throughout American industry. The need for larger, more complex facilities to support both university and industrial materials and chemistry research was also growing. Some of these facilities, such as synchrotron light sources, require expertise in the design and construction of accelerators.

At LBL, our materials and chemistry research programs have grown in vitality and excellence. Our Accelerator and Fusion Research Division, in conjunction with Exxon, led the design and construction of the wiggler beamline at the Stanford Synchrotron Radiation Laboratory, the world's brightest x-ray source. We are providing a national user community of materials scientists, surface chemists and biologists with unique materials characterization facilities at our National Center for Electron Microscopy, which began full operation in FY 1983. All of these activities were supported by BES programs.

Our work with Exxon is one indication of how LBL is working closer with industry so that our basic scientific results can contribute to our nation's technological progress. Our materials and chemistry research programs have led the way for LBL in this area. With the support of the Materials Science program in BES, and the strong support of Congress, our Center for Advanced Materials (CAM) began operation in FY 1984. Its basic research programs in catalysis, polymers, ceramics, electronic materials and innovative instrumentation have been designed with industry guidance. Each program undergoes a yearly review by an industry advisory panel, and several industrial laboratories have sent their scientists for extended tours of duty at CAM. In seventeen months, their scientific progress has been impressive. The next step is to provide these programs a modern home with up-to-date equipment that is conducive to more effective collaboration with industry and among our own staff. The FY 1986 budget request for CAM construction will enable us to move toward this goal.

An important step in strengthening the Laboratory's capabilities in vacuum ultraviolet and soft x-ray radiation was to establish the Center for X-Ray Optics which is supported by industry, BES, and other federal agencies. The broad charter of the Center is to develop technologies required for the utilization of emerging sources of vacuum ultraviolet and soft x-ray radiation, to participate in the development of these new sources, and to use newly developed capabilities in demonstration experiments. Its personnel--including physicists with backgrounds in optics and accelerator design, together with engineers and spectroscopists--reflect its interdisciplinary foundation.

Along with our accelerator designers, this group would also be part of the nucleus for a future role for LBL as the operator of a new national user facility, a next-generation synchrotron light source. We are pleased to see both the National Academy of Sciences Major Facilities for Materials Research panel and, most recently, the ERAB Materials Facilities _ad hoc_ Review Committee recognize the vital need for new major facilities for materials research. We look forward to participating in the development and research at these new national user facilities, and believe that LBL would be an ideal location for the soft x-ray source that has been recommended. This machine would serve the materials characterization needs of DOE's energy and national security missions as well as a broad scientific community of chemists, atomic physicists, biologists, and materials engineers and scientists.

All of the new initiatives I have just discussed have occurred despite uncertain budgetary conditions, and all of them have been supported by funds from BES programs. The first point is important because I believe that the scientific vitality and creativity at a national laboratory depends on fully utilizing the existing and developing resources of that laboratory as they emerge. The second point is equally important as it illustrates the overall direction of LBL's research efforts.

Our reorientation to a BES-based laboratory is well on its way. LBL has 35 members of the prestigious National Academy of Science and the National Academy of Engineering, and 27 of those 35 work in BES-supported areas. Even more important, LBL has six of the Top 100 Young Scientists in the United States Under 40, as reported by _Science Digest_ last December, and they are almost totally supported by BES funds. This successful reorientation means that reduced or steady-state funding levels for BES programs threaten these valuable new initiatives and will have a detrimental effect on the institutional health and vitality of LBL.

Laboratory Budget Outlook

Adjusting to the unpredictabilities of the federal budget process is unfortunately nothing new for LBL. The energy research budget in fiscal years

1981 and 1982 was substantially below previous budget levels. It hit LBL the hardest of any of the national laboratories. We were forced to layoff almost 600 people, or 19% of our workforce. Personnel and budgetary cuts were made in administrative and institutional support areas but deep cuts also had to be made in long-term scientific programs. These programs suffered grave damage, as might be expected, but the reduction in administrative and technical support services affected the morale and research productivity of the entire laboratory.

The two years following these cutbacks, fiscal years 1983 and 1984, were years of rebuilding at LBL. As I previously explained, the Center for Advanced Materials was launched, and other programs were restructured and strengthened within the overall LBL funding plan. These actions were made possible with the strengthened funding commitment by the Administration and Congress for strong federal support of basic science as the central component of our nation's research and development efforts.

It is thus disappointing to report that LBL's operating funds for DOE programs in this fiscal year, FY 1985, will actually be $2.6 million, or 3%, lower than the FY 1984 budget. When the LBL inflation factor is included, this becomes a 10% reduction in real operating funds. This reduction was not expected; indeed, we had anticipated an increase in operating funds based on the Administration's budget submission and its reception by the Congress that would allow us to sustain our overall activities but with some program redirection. This increase, however, was eliminated by adjustments to specific parts of the energy research budget that had negative consequences for many research programs.

These reductions have forced us to lay off 98 people. We may have to lay off even more people before the end of September. We have tried to make most of these reductions in our administrative and support services, but there have been reductions in some scientific programs. The progress LBL had made in strengthening and revitalizing its staff and scientific programs over the past two years was halted in its tracks.

Now your Subcommittee has before it the Department of Energy's proposed Basic Energy Sciences budget for fiscal year 1986, which threatens to reverse much of the progress we have made in developing LBL into a strong multiprogram national laboratory. The projected overall BES budget is 3% lower than the FY 1985 budget, and over 7% lower when inflation is included. The reduction is even more significant when only those programs affecting LBL are examined. An initial reading of those figures shows that LBL's operating funds from DOE in FY 1986 would be $6.2 million, or 5.5% below FY 1985's budget. This represents a cut of over 14% in real operating funds. On top of FY 1985's reduction, that means that LBL's DOE operating budget will drop almost 24% in real terms in two years. Disastrous is not too strong a word to describe the impact that these cuts will have on the quality and productivity of our scientific research, and on the health of the institutional structure that is LBL.

Our preliminary calculations are that the proposed FY 1986 LBL budget would mean a reduction in force of over 300 people. Most of these reductions would have to be made by July 1 so that we start the FY 1986 year with the budgeted amount of employees. These cuts will not all occur in administrative and engineering support, since most of the cuts in FY 1985 have been made in those areas; significant programmatic cuts are required that would curtail or eliminate major programs at LBL.

It may come as a surprise to some members of Congress that such major reductions are occurring at LBL while the federal government's research and development budget continues to rise. The explanation is a relatively simple one. For FY 1986, overall federal R&D spending is slated to rise 2% over FY 1985, but the figures look very different when broken down by agency and mission. R&D funding at the Department of Defense, for instance, is budgeted to rise about 22%, and funding for the National Science Foundation is to rise 7%. DOE funding of R&D, on the other hand, is scheduled to decrease by 2%, and when the increase in military R&D is subtracted, fundamental research actually drops by 8.4%. The increases in federal R&D spending, therefore, are highly selective and are not reaching the performers of DOE basic research at national laboratories and universities.

Effects of Budget and Staff Reductions on LBL Research Programs

Let me take a moment to discuss several examples of how LBL scientists are contributing to the technological advances that strengthen our nation, and how these areas would be affected by the 1986 budget cuts. A group of LBL physicists and electrical engineers have critically evaluated solid state electronics for high frequency excitation of fluorescent lighting. This basic application has been transferred to the private sector where innovative new ballasts for fluorescent lights have been developed and are on the market. Some estimates indicate the energy savings achieved by these ballasts will be far more than $1 billion annually, and will keep the involved U.S. companies at the forefront of lighting techniques and design. This highly successful program will face difficult times because of the 1986 budget.

Our pioneering developments in medical diagnostics and treatment provide other examples. Positron Emission Tomography was pioneered at LBL, and we continue to make great contributions to furthering medical diagnostic techniques. We now have developed new detectors for this device which, if commercialized by the private sector, could reduce diagnostic surgery and contribute to more cost effective health care. Unfortunately, the Basic Energy Sciences funding of this program has diminished significantly, forcing a redirection in our scientific efforts.

The National Center for Electron Microscopy (NCEM), a national user facility funded by BES, contains the most powerful electron microscope in the United States and the highest resolution microscope in the world. It has proven extremely useful in many scientific areas. In the materials science fields, an analysis of metal structures using NCEM's facilities have lead to new heat treatment of alloys that are now coming into widespread use. We have also conducted fundamental studies of alloy properties that have facilitated substitutions of less expensive elements for more costly alloy materials. CAM's Electronic Materials program, exploring gallium arsenide as a possible substitute for silicon in very high speed computers, has used NCEM's unique microscopes to image rows of atoms in this material for the very first time. The information that can be developed from these images may help accelerate the use of this material by American semiconductor companies. The 1986 budget will unfortunately mean that NCEM's continued development as a state-of-the-art user facility will be impaired, and the amount of time it will be available for use will decline.

A related activity is the development, in CAM's Surface Science Instrumentation program, of a scanning tunneling microscope. This unique instrument allows for further analysis and characterization of materials samples on the atomic level. Funded through the BES Materials Science program, this promising area of research will face severe limitations in the 1986 budget.

At the Center for Advanced Materials (CAM), a major new initiative started in FY 1984 despite the instability of the budget, programs are nearing a standstill as reduced funding impedes the initial growth they require to get off the ground. Our industry advisory panels have made it clear that companies are unwilling to become fully involved in CAM research efforts until a successful track record of federal support has been established. The opportunity to establish CAM as a successful program based on a good foundation will be lost if CAM's funding remains stable at best.

In the Geosciences area, LBL and DOE may have to default on our commitment to participate in the Continental Scientific Drilling Program. The start of our planned hazardous waste research and underground research laboratory will not be possible. Two outstanding new initiatives, the establishment of a major solid-state nuclear magnetic resonance laboratory and the production of chemical elements beyond number 100 for the systematic study of their properties, will have to be postponed or eliminated.

User Facilities and Plant Maintenance. Our user facilities will be seriously affected by the budget reductions. The availability of the National Center for Electron Microscopy to users, as previously mentioned, will be reduced. Operation of the Bevalac will be cut back to about 7-1/2 months, compared to an optimal level of 9 or 10 months--a level that we achieved in 1984 and that still allowed for substantial machine upgrades and facility improvements. A much-reduced level will not only adversely affect nuclear science research and student education, but also have a serious impact on the cancer therapy program, which demands a measure of continuity in its treatment protocols. The reductions in the fusion program may force the shutdown of the Neutral Beam Engineering Test Facility, and will mean major cuts in our associated research programs. We share the concerns expressed by many members of Congress that only facilities absolutely essential to scientific progress be constructed, and that those facilities be used to their full potential. The latter concern is particularly timely as more facilities are proposed and the budgets providing for their operating expenses do not grow in tandem. Such facilities, whether they support basic research or technology development, are crucial reasons for the existence of national laboratories. LBL is committed to developing and operating world-class user facilities that can contribute broadly to all of DOE's missions, but Congress and the Administration must realize that the scientific results we all desire from these facilities will only come when these facilities are operated at their most productive level. Most of our national user facilities and laboratory space were constructed between 25 and 40 years ago. The average age of our laboratory space is about 27 years old. The 10% reduction in DOE's 1986 R&D capital expenditure budget reflects an undercapitalization of our national laboratory science facilities, a loss after inflation of about 17%. At LBL alone we need $123 million in capital expenditure just to "get well". I would be pleased to provide some detailed information that describes these capital needs at your request. Our pre-eminence in science will not last into the next decade unless we act soon. You and I are concerned about the financial burden of these investments on the next generation, but unless we undertake capital projects now, the next generation will have little scientific capital that is the basis of continued innovation and technical growth.

General Administrative Expenses. Each national laboratory, including LBL, funds its general administrative and institutional expenses through a fixed percentage charge on each scientific program. As program funds go down, so does the total dollar amount of this charge. While program funds can continue to drop, there is an absolute cost for operating LBL that has to be maintained in order to provide the essential services that keep a world-class laboratory operating and productive. A significant reduction in funding of BES programs, therefore, causes damage not only to those specific BES programs but to the overall institution and the essential support for other programs.

Conclusions

National laboratories like LBL that perform basic research are a long-term investment in our nation's economic and industrial future. The health of these laboratories, both programmatically and institutionally, will have a major impact on the ability of American industry to remain technologically competitive. Important to the productivity of national laboratories is a stable research environment. Successful research results are obtained from scientists who dedicate years of their lives, and graduate students who often commit the direction of their professional future, to long-range research objectives. These experiments can take many years to produce useful results, and cannot simply be started up or shut down when money becomes available. To be productive there must be a continuing commitment on the part of project sponsors to maintain the research environment that nurtures such projects.

Without this commitment to operational stability, there will be a significant deterioration in the quality of scientific research performed at national laboratories. Scientists will look for more stable environments in which they can perform their research. Recruiting of new scientists and engineers, an ongoing process essential to the vitality of a national laboratory, will become much more difficult. Graduate and undergraduate students, looking at the ups and downs of federal support for basic research, many rethink their commitment to fields in which their professional future would always be in question. Our nation will be the loser as students choose areas of study less relevant to a secure energy and economic future that is increasingly underpinned by research and innovation.

Discussion of the proposed 1986 budget cuts bring to mind a larger concern than simply the year-to-year ups and downs in LBL's budget, and that is the role of the DOE national laboratories in the overall science policy of the United States. You have asked me to comment on the Science and Technology Committee's comprehensive review of how our nation's science policy is formulated and implemented. This effort is to be applauded, since a periodic assessment of where we plan to go and how we plan to get there is exceedingly useful. The proposed review of the role of government laboratories in the federal support of science is especially welcome. We at LBL are fully convinced that the national laboratories have an important role to play in the development of scientific and technical knowledge. We are not, however, certain that this conviction is shared by others within the federal government. As I discussed before, a scientifically productive national laboratory must at least receive stable funding to carry out its mission. That funding stability is not evident in the 1985 or 1986 budgets, and it appears to indicate a lack of support for the national laboratories and their missions. A detailed examination and debate on these questions will help to better define the role of, and support for, the national laboratories, and we look forward to helping in that process in whatever way we can.

Let me comment on the initial agenda of the Task Force. We are especially interested in five areas of this agenda:

1. The institutional framework of basic research;
2. Education and manpower;.
3. Funding trends and mechanisms;
4. Mission agency research; and
5. The importance of congressional roles.

Each of these areas, to differing extents, has been addressed in today's testimony. A specific question I would recommend to the Committee, however, is the extent to which once programs are begun, stable funding could be maintained through their completion . As I outlined before, the major problem facing federally funded science today is the uncertainty of the budget process. This uncertainty results in slower development of scientific results, less productive research and less commitment on the part of scientists, graduate students and industries to those research activities. Perhaps this uncertainty is inherent in the federal budget process, and therefore will always be with us. If this is the case, the Administration and Congress must recognize that the unfortunate results of this uncertainty will be as outlined above. Hopefully we can regard our scientific capital as a wise investment in our future and provide some basis for overall institutional stability and quality for achieving identified scientific research missions and objectives.

Finally, I would like to thank the Subcommittee for inviting us here today. The importance of basic, fundamental research to the future of our nation's technology-driven economy cannot be overstated. Yet it is a subject not well understood by the American public, or many of our nation's lawmakers. The members of this Subcommittee are a rare exception, and I hope that today's deliberations can be used to educate your colleagues about the importance of federal funding for basic scientific research.

Mr. MINETA. Thank you very much, Dr. Shirley.

Dr. Postma.

STATEMENT OF DR. HERMAN POSTMA, DIRECTOR, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN

Dr. POSTMA. Thank you. I am Herman Postma, Director of the Oak Ridge National Laboratory, and I can only underscore what my colleagues have stated; and I also have some bad news and some good news, and I'll talk about the bad news first, things that they did not cover.

Our laboratory is affected in similar ways to my colleagues'; I will not go into those details, however. I will add that there are two concerns. There is, first, some good news that, relatively speaking, Basic Energy Sciences was cut less than other portions of the Department of Energy, and that has been true for a number of years. But nonetheless, that does have an impact.

There are two hidden factors in the budget that I think need bringing out. One is that the congressionally mandated projects were not included. These are at Columbia, Florida State, and Oregon State. If one includes those in the budget, then that makes an impact of approximately $20 million. If the Committee decides that they are—as they have in the past—to be included in the budget, that means that the reductions in the Basic Energy Sciences, if it comes out of existing budgets, will be decreased by another 5 or 6 percent on top of those reductions that have already appeared.

The other loaded gun, I should say, is that there is—it was referred to earlier today—that there were to be no new starts. That is also disturbing. Under the conditions of the tight budget I can expect that there would be few new starts, but no is a very absolute command. There is—new science requires new starts, and there is no such thing as old science that is any good. So we have, as a matter of fact, in order to hold up the hopes of the people, in order to give them the directions to go, allow a few new starts. And Dr. Seitz did give some priorities of areas in material sciences which their Committee had come to. I would urge that the committee reverse the dictum of no new starts and maybe modify it to a few new starts, but also put into the budget some money to allow the planning and studying for the things that Dr. Seitz recommended. It does not mean a commitment to build but it does mean a commitment to plan, to come up with the kinds of designs, and to come up with the R&D necessary to support those particular projects.

Next there's some good news. The Basic Energy Sciences programs at ORNL are, I think, very healthy. I list a number of scientific results in the testimony that would tend to show that, and I'm not going to go into any of those, but there are several facets to the kinds of Basic Energy Sciences at any laboratory. There are the scientific results that contribute to the body of knowledge; there is the support of technologies at a multiprogram laboratory, particularly such as Oak Ridge and at Argonne—there are a number of technologies for whom the Basic Energy Sciences, as Dr. Schriesheim has indicated, are absolutely necessary in order to continue the base by which those technologies will go into new areas and actually benefit the country. That's the second area.

The third area is that of user facilities. These magnificent facilities that are unique in the country are open to users from all over the place, allowing the small scientist as an individual to use big facilities, and therefore do big science.

The fourth area is that of recent scientific discoveries. Last year, I think the Committee heard testimony from the Laboratory at Oak Ridge about nickel aluminides, a particular very good alloy. I'm happy to report that a number of industries have cooperated with us, and that is becoming rapidly commercialized, specifically Cabot Research and Cummings Diesel.

What I want to do is give one example today, which I will pass around, of something that came to fruition this year that pays for the entire cost of the Basic Energy Sciences Program, each and every year from now on. Now, every year I think that one of the laboratories, or even all of them, can point to a specific thing that has that kind of particular impact upon society. That also would support both Oak Ridge and Argonne in its entirely if those benefits really come to be realized, and that is a program that grew out of the Basic Energy Sciences. I'm talking about a program in which a user of our medium-sized facility from the University of Alabama at Birmingham cooperated with our surface scientist groups, which include both physics and chemistry, to come up with a way to improve hip joints—and I'd like to pass some around, if I may—I am going to pass around a hip joint and a knee joint. Now, there are approximately 160,000 operations performed per year to implant, into humans, joints because of hip problems or knee problems. Now, these particular items have been on the market for a number of years; however, it is well known that once placed in the body, that the body fluids attack these very special alloys, causing corrosion and erosion to take place—Basic Energy Sciences problems. This shortens the life of such implants to, in some cases, 4 years, to perhaps 10 years. In shortening the life, that means the operation has to be performed again; and my understanding is that this $2 billion a year industry has about $400 to $500 million a year of repairs to do as a result of this kind of activity.

Well, through the implantation of nitrogen ions through accelerators—small to medium scale science—one is able to put nitrogen in the surface of these particular alloys and make them essentially impervious to corrosion. Our estimates and our tests show that these will last in the body approximately 400 years, which I think is adequate to prevent replacement for most of us. [Laughter.]

Now, you can see that just the cost of replacement operations pays for the entire Basic Energy Sciences programs, and it came out of Basic Energy Sciences. And in addition, if you take into account the lost time on jobs and suffering by all these individuals as they had to be operated on again, you'll find that much greater savings have resulted.

Now, I would say that this is perhaps a dramatic thing that comes out because it relates to people that have severe medical difficulties brought on by old age or not taking enough calcium or other activities that they may have engaged in, but the end result is that the Basic Energy Sciences Program, which is in this particular activity—not for knee joints, not for hip joints—but for the fact of studying the basic sciences of surfaces, because surfaces are important to catalysis, surfaces are important to tribology, the study of friction, and surfaces are important to corrosion and erosion. And in most energy technologies you will run across many of these kinds of sciences in trying to seek cures.

So we think there's a particular success story. I think that every year we can come up with one or more similar success stories that essentially pay for the entire enterprise for the foreseeable future. That's not the purpose of that particular enterprise; these are little crumbs off the table that happen to occur, and are very important.

Well, we see several trends occurring in the Basic Energy Sciences. All are healthy—the collaboration with universities, with industry has grown tremendously. The use of these unique facilities leading to such things as this have been important at all the national laboratories. The international cooperation has been extremely important. But perhaps most important is the fact that at a laboratory, the integration of all parts of Basic Energy Sciences, the integration of the Basic Energy Sciences with the technologies, and the integration of the Basic Energy Sciences with the other communities is an extremely important and very healthy factor. In fact, if you equate the activity of integration of all of these things into something which I think is very important, it's something we shall call meshing, you can say that the national laboratories and the Basic Energy Sciences make a mesh out of things, and that, I think, is very important to the health of science in this country.

Dr. **Postma**. That concludes my testimony; however, I would, if you would permit me, introduce into the record one article out of this month's High Technology magazine, February 1985, which includes the whole area of ion implantation for which Basic Energy Sciences can take a very considerable credit, and this committee can, for having permitted that activity to grow in the last few years to something which is an extremely important area of science, both from the area of basic sciences, but also in its application.

Thank you.

Mr. **Mineta**. Thank you very much, Dr. Postma. Given the consideration of seniority around here, I'm not sure that some of us would really be pleased with the implant kind of examples you were showing around here. [Laughter.]

Dr. **Postma**. Well, if we could guarantee the 400 years for the rest of you, that would be OK, wouldn't it? [Laughter.]

[The prepared statement of Dr. Postma follows:]

BASIC ENERGY SCIENCES
AT THE OAK RIDGE NATIONAL LABORATORY

Herman Postma
Director

TESTIMONY BEFORE THE
SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS
COMMITTEE ON SCIENCE AND TECHNOLOGY
February 28, 1985

My name is Herman Postma. I am Director of the Oak Ridge National Laboratory and it is an honor and a pleasure to offer my testimony to the Committee on Science and Technology. I am both pleased and troubled by the FY-86 DOE budget for Basic Energy Sciences and its portent for the basic research program, not only at the Oak Ridge National Laboratory but for all BES programs. I am pleased because on the face of it the BES budget has suffered fewer cuts than many other parts of the Department of Energy and seems to be getting administration support at a time of budgetary difficulties caused by the very large deficits. Yet this must be realized in the context that the DOE has had amongst the largest overall budget cuts of any agency not only in the current year but over the past four years.

While in any budget there are areas of elation and concern, I am particularly troubled by two matters that I will discuss in turn. First, the budget contains no funding for what the Department calls Congressionally Mandated Projects which include the building completion at Columbia University, the continued funds for the computer center at Florida State University, and the next stage of construction at the University of Oregon. Together I estimate that this amounts to a sum between $20-25 million depending on the readiness of the project at the University of Oregon. It is, in my view, unrealistic to expect that the Congress will not continue to fund these projects since it has agreed to fund them in the past several years. If that money came from the $409 million proposed by the Department, it would create a very serious funding problem for all the Laboratories as well as for university-based research funded by the Department. If we assume that Congressionally Mandated Projects in FY-86 are funded at a level of about $21.5 million, and if the cost-of-living increase between FY-85 and FY-86 is 5%, and if support for the operation of major facilities keeps up with inflation, the net effect on Basic Energy Sciences programs will be a real decrease in funding for research of 12.8%, not 3.0% as implied by the total budget request. This is a very serious loss of support and would lead to additional constrictions in programs which are flourishing, productive, and necessary. I therefore urge the Committee, if it proposes to fund the Congressionally Mandated Projects, that these be in addition to the request and not distributed as in the past among its various programs.

My second problem has to do with the overall policy enunciated by the Office of Management and Budget which calls for "no new starts". No new starts is a policy that may be tenable in many areas of the Federal Government. It usually means that the status quo will be preserved, that work that has been funded in the past will continue and that the same objectives can be reached in the fiscal year with no new starts. In science, however, matters are quite different. Science by its very nature proceeds by new starts. The objective of science is to discover new things about the world around us and to apply them to human welfare. In the context of science, no new starts can mean no new science and there is no such thing as old science. I am particularly concerned that the dictum of no new science will delay for a year the beginning implementation of the recommendations of the report of the Seitz-Eastman Committee of the National Research Council. Delay in this matter can do nothing but set back our capabilities in the study of materials, both basic and applied, and will assure that the leadership in neutron scattering, for example, continues to reside with the Europeans and that the development of a 6 GeV light source will happen in Europe before it happens here. Instead of no new starts, I would advocate "few new starts", allowing planning for real advances in the future. Perhaps some stretching out is inevitable, but no is too absolute.

I would therefore urge the Committee to request that the Office of Basic Energy Sciences support the R & D and preliminary engineering studies of a site-independent design for the 6 GeV synchrotron radiation facility and an advanced steady state neutron facility as recommended by the Seitz-Eastman report out of available funds in FY-86. I further urge the Committee to request that next year the Department submit a plan beginning with FY-87 by which these two major research facilities will be realized and to include a request for the necessary preconstruction R & D. Only in this way can the country assure itself of regaining the leadership in modern materials research, an area that by all accounts and through the study of numerous committees is acknowledged to be vital to the progress of science and technology in the U. S. and that has contributed so much to our welfare in the past. The planning and R & D are urgent for progress, the implementation depends on a combination of need and resources.

Basic Energy Sciences Programs at ORNL

I am pleased to report to the Committee that the BES program at the Oak Ridge National Laboratory is doing well. We measure our success in this field by a variety of criteria: (1) scientific productivity, that is new interesting results that contribute to the advance of science; (2) the effectiveness of BES programs in underpinning the energy technologies; (3) the reliable operation of major facilities for the benefit of outside users; and (4) the emergence of new ideas which directly impact energy technology and are of ultimate benefit to the country. It is obviously impossible for me to dwell exhaustively on these topics; I will therefore mention only a few so that the Committee may gain some understanding both of our most recent accomplishments and our problems.

I. Scientific Results. One area of science that is high on everybody's list these days is the study of surfaces. Understanding surfaces is important as an end in itself but it is also necessary in a variety of fields such as catalysis, corrosion, erosion, welding, etc. By the application of the most modern low energy electron diffraction spectroscopy and comparison with complex theoretical calculations, Oak Ridge scientists are able to determine atomic positions of surfaces to better than 0.02 Å which is 2-5 times better than previous determinations. The results indicate that for a number of metals including copper, silver and aluminum there is a contraction between the first two layers and an expansion between the second and third layers of a crystal as compared to bulk material spacings. Related theoretical calculations have predicted a rippling in the surface of an ordered aluminum nickel alloy and subsequent experiments have shown that prediction to be correct.

We and our outside users do a great deal of work with neutrons at our High Flux Isotope Reactor. In one series of experiments our chemists have determined the arrangement of water molecules that surround rare earth chlorides in aqueous solutions. In another experiment at 2.7 mK they have observed the ordering of nuclear spins in praesodymium-copper crystals. These experiments may indeed sound esoteric, but they contribute in important ways to our understanding of aqueous solutions and nuclear magnetism. Both of these have important scientific consequences and are almost certain to have important applications in the future.

In a very different kind of research, our analytical chemists have developed a set of coupled mass spectrometers that, because of their extreme sensitivity, 10^{-7} to 10^{-15} grams, may prove useful in sniffing out explosives and other materials at airports and other locations.

II. Support of Technologies. At a National Laboratory such as ORNL a number of important technologies is being pursued. Among them is fission, fusion, and conservation. On purpose our BES program is closely linked to these technologies. For example, the study of chemical properties of actinides provides the necessary advances for processing nuclear fuel and confining nuclear wastes. The extraordinary success in obtaining the world's first results of highly charged ions in ion-electron recombination process allows fusion scientists to calculate losses from magnetically confined plasmas with much greater certainty. Advances in the understanding of crack propagation in ceramics are of great importance to the conservation programs that deal with the introduction of ceramic components into internal combustion engines. In a broad sense the Basic Energy Sciences program provides data and techniques to the applied programs and these in turn provide problems and motivation that direct parts of the basic program into the required fields of study. Collaboration between the technologies and the sciences is most effective when it is organizationally integrated as in fact it is in many of our research divisions. Nothing succeeds like propinquity is a statement that applies to the transfer of scientific ideas as readily as it does to politics.

III. User Facilities. The Oak Ridge National Laboratory takes its role as a provider of large or unique research facilities to the Nation's scientific community very seriously. In nuclear physics and basic energy sciences we have five outstanding facilities which are listed in Table I. In the past year these facilities have been used by 337 scientists from outside the Laboratory and each facility has been used by them for a significant part of its capacity, between 30 and 80% as illustrated in the same Table. Two facilities are currently under construction. One is the National Low Temperature Neutron Irradiation Facility and the other is the X-ray and Vacuum Ultra Violet Experimental Station at the National Synchrotron Light Source at Brookhaven National Laboratory.

For the past few years I have been concerned that the United States has lost its leadership in the use of neutrons for the study of condensed matter. Currently the French-German-British research reactor at Grenoble outclasses anything this country has by about an order of magnitude. As a consequence, over 1000 European scientists use this reactor annually, and it is no wonder that with superior tools at their disposal they have outdistanced us in many areas. We at Oak Ridge have used exploratory funds for the past two years to complete a conceptual study and preliminary design of what a modern research reactor should look like and what kind of facilities it should provide to the neutron user community in this country. I am pleased to be able to report that our scientists and engineers have come up with a design which outclasses the Grenoble reactor by about a factor of 7, and which would regain for this country leadership in a most important area of materials research. The new reactor is designed to be useful not only for neutron scattering but also for the study of radiation damage for fusion and fission reactors and for the production of transplutonium elements such as ^{254}Es and ^{252}Cf. We were gratified that the Seitz-Eastman committee (National Academy of Sciences Committee on Major Facilities for Materials Research and Related Disciplines) recommended that the country should proceed immediately with an engineering design program necessary to produce a conceptual design for such a reactor and that indeed a reactor of this type would be an essential component of U. S. materials research capability in the long term. The Energy Research Advisory Board panel charged with reviewing the Seitz-Eastman report concurs with these conclusions in a letter written to the Chairman of ERAB.

IV. Recent Significant Discoveries. It has been understood for a long time that the pursuit of basic knowledge results not only in an increase in intellectual capital and understanding of the world around us but also produces discoveries, inventions and advances that enhance humanity's well-being. The recent history at the Oak Ridge National Laboratory provides ample illustration of this fact. This Committee has previously heard testimony about ORNL's revolutionary discoveries of ductile intermetallic compounds of nickel and aluminum that have resulted in alloys of unprecendented high temperature strength, and I am pleased to report that even after a short incubation period of a few years we are collaborating with many industries in the transportation sector toward commercial applications of this discovery. In quite another area, that of medical prosthesis, we have been successful, in collaboration with the University of Alabama at Birmingham, in developing corrosion- and erosion-resistant hip joint and knee joint replacements which are expected to eliminate the need for the current practice of replacing these artificial joints several times in a person's lifetime. Let me elaborate a little on this discovery. It is estimated that 100,000 hip joints and 60,000 knee replacements are performed annually. Imagine the peace of mind and relief from pain of all of these people as they realize that they will not have to undergo this operation again in their lifetime. But quite apart from that, let us consider the economic impact. If, because of the research in solid state physics, just a quarter of the artificial joints will not have to be replaced, the net savings to the country is $400 million or about equal to the total BES budget for FY-86.

There are many other areas of materials research carried out at the Oak Ridge National Laboratory that have the potential of enhancing the U. S. economic position. They include the development of tough ceramics which, combined with a deeper understanding of welding and joining, has recently culminated in our ability to braze partially stabilized zirconia ceramics onto cast iron (this research, funded by Conservation, explores a combination of materials one would use to line piston heads with ceramics); or the advance of our understanding of industrial polymers through the use of the National Science Foundation funded Small Angle Scattering Facility on the Basic Energy Sciences funded High Flux Isotope Reactor. In the chemical sciences, recent advances in the separation of uranium from phosphate ore or silver from photographic waste liquor were quickly adopted by industry as have a number of analytical techniques developed at Oak Ridge.

Support of Major Facilities

One of the cornerstones of the Basic Energy Sciences program at a Laboratory such as ORNL is the existence of large and unique facilities. They are a true national treasure and existing ones could not be duplicated today except at exorbitant cost. In this connection I am pleased that the budget finally calls for reasonable support for the stable isotope program which the Laboratory operates for the whole country and which, at the level of $1.7 million for FY-86, can operate in an orderly fashion to supply isotopes for medical purposes, for research, and for industrial applications. I strongly urge the Committee to support this level of funding for stable isotopes.

Less well known perhaps is the Transuranium Processing Plant (TRU) which is the Nation's only source of ^{252}Cf. This isotope fissions spontaneously and has a long enough half-life to be useful as a portable neutron source. Currently the Air Force is experimenting with ^{252}Cf as a method of finding flaws in air frames and engines without having to disassemble the aircraft. Neutrons have an advantage over x-rays in that they can penetrate massive structures much more easily, and neutron radiography has been successfully used to detect hidden defects in large or absorbing structures. We expect increasing demand for ^{252}Cf in the future. This is happening at the same time as the scientific community is becoming increasingly aware of the importance of the study of very heavy elements, atomic number 103 to 109, and again TRU, in combination with our high flux reactor HFIR, is the only facility in the world that can produce them. We are therefore pleased to see major facilities funded if not comfortably, then at a level of austerity that allows us to use them productively. I ask the Committee to support the Department's budget submission in this regard.

ORNL Trends in Basic Research

I discern a continuing and growing trend in the BES-funded programs of the Oak Ridge National Laboratory toward increased user mode operation of large and small facilities operated by the Laboratory and used by scientists from universities, other laboratories, and industry. I also see greatly increased interactions with industry (having already grown by 500% in the last five years). The Laboratory's capabilities to synthesize, measure, and characterize are not available to any one industry and our facilities and expert staff can therefore prove extremely attractive. We currently have collaborations with the Cabot Corporation, we are at the threshold of a significant interaction with the American Iron and Steel Institute, and we work diligently with companies such as Garrett, Cummins, Johnson & Johnson, IBM, AT & T and dozens of others. I also see increased collaboration with other countries in sharing facilities and experiments - a trend typified in BES by Japanese at HFIR. It is fair to say that all of these interactions depend in an essential way on the existence of a strong multifaceted basic research program at ORNL and that it is the high quality of this program that attracts industry and in this sense makes the Laboratory immediately useful as a contributor to the national wealth.

TABLE I

UTILIZATION OF MAJOR USER FACILITIES IN FY-1984*

FACILITY	NO. OF OUTSIDE USERS	% USER TIME
HHIRF (HEAVY ION RESEARCH)	122	48
NCSASR (SANS AND SAXS)	86	83
HFIR (NEUTRON SCATTERING)	44	45
SMAC (ION-SOLID INTERACTIONS)	43	48
SHARE (ELECTRON MICROSCOPES)	42	30
TOTAL OUTSIDE USERS	337	

*NCSASR AND HFIR DATA FROM FY-1983 DUE TO SCHEDULED REACTOR SHUTDOWN IN 1984.

10-30-84

Many materials gain valuable new properties when bombarded with focused plasmas

ION-BEAM IMPLANTATION

by Nicholas Basta

The science of metallurgy, among the first of man's crafts, has long been limited by strict rules about which compounds could be mixed together. Many metals simply will not dissolve in each other, and hence form poor alloys or coatings.

But recent research in atomic physics is providing a way around these strictures. Atoms of practically any ionizable element are being excited to high speeds and shot into the surface of almost any type of solid. (Ionization is the process by which atoms or groups of atoms assume a net electrical charge by losing or gaining electrons.) The result is an intimate mixing of heretofore incompatible elements, and a repeal of some age-old laws of metallurgy.

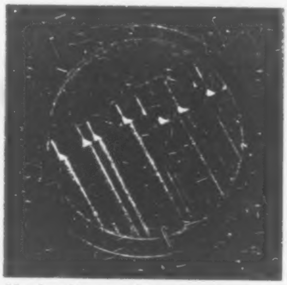
The new alchemy, called ion-beam processing or ion-beam implantation, is already a common practice in the semiconductor industry, where silicon is doped to alter its electrical properties. The most recent developments are in the treatment of metal, ceramic, or polymeric surfaces to upgrade hardness, optical properties, corrosion resistance, electrical conductivity, and other characteristics. Such elements as nitrogen, argon, boron, platinum, rhodium, phosphorus, chromium, and molybdenum have been implanted in steel (and many of its alloys), titanium, and copper, as well as in glasses, ceramics, and organic polymers.

"If we see a 100–200% improvement in surface properties through ion-beam processing, that's a failure to us," says Piran Sioshansi, director of surface modifications at Spire Corp. (Bedford, Mass.). "We're looking for a 1000% improvement."

The conversion of a gas or a vapor to a plasma (a cloud of ions) is not new. But using the plasma as a pure, focused beam to bombard a target workpiece occupies a leading edge of materials research.

Ion implantation is conducted in a vacuum to prevent chemical contamination and ion scattering. The typical ion-beam generator, called a Freeman source, is a metal cylinder containing a filament that throws off electrons when electrically charged. The element to be implanted (or a compound containing the element) is first vaporized, then ionized as it collides with the electrons. The resulting ions can be either positive or negative, depending on the element.

If metal ions are to be implanted, the metal must first be converted into a chemical that vaporizes readily. Titanium, for example, can be converted to titanium chloride. In this case, ionization produces a vapor consisting of both titanium and chlorine ions; the latter can be extracted by magnetic fields.



Metalworking punches are ion-implanted inside a vacuum chamber. Among the benefits imparted by the process are longer tool life, less corrosion, and cleaner, faster cutting. (Photo courtesy of Zymet)

A combination of magnets and electric coils can then be used to direct, purify, and concentrate the mass of ions into a tightly focused beam. The energized beam smashes into the target material (called the substrate); the beam penetrates to a depth of a few microns, displacing some of the substrate's atoms and causing a cascade of additional collisions. When a metal ion is implanted in a metal substrate, the result is an alloy of the two, usually in a highly amorphous state with no grain boundaries. The new surface usually shares some of the properties of both materials, but a synergism can also occur, where the surface is tougher or more corrosion-resistant than its constituents.

Because nitrogen implantation is the process most heavily researched and easiest to perform, it is among the first commercial applications. Generally, the nitrogen ions—which emerge from the ionization chamber as part of a 50-50 mixture of ions and charged molecules—make metals harder and more durable, reduce surface flaws and other defects, and prevent spalling (a peeling away of the surface layer) and other types of degradation.

One example is nitrogen treatment of surgical bone implants. In many such prostheses, this treatment reduces wear rates by a factor of 400 or more, according to research conducted at both Oak Ridge National Laboratory (Oak Ridge, Tenn.) and the Harwell facility of England's Atomic Energy Authority.

The implant of greatest interest—the artificial hip joint—is usually an alloy of titanium, aluminum, and vanadium; when implanted, its ball-shaped end fits inside a polyethylene cup. In time, body fluids wear away bits of surface metal, which become embedded in the cup and cause abrasion and premature failure of the prosthesis. As a result, many implanted joints have a useful lifetime of only 10–15 years.

Treating the implant with nitrogen, and sometimes carbon, reduces the surface wear to negligible levels and promises to greatly extend the useful life of the hip joint—theoretically by a factor of 10, well beyond the lifetime of the patient. (While nitrogen implantation may improve wear rates of the treated metal by hundreds of times, "useful life" depends on several factors—the patient's age and lifestyle, for example, and the durability of the metal-to-bone bond.) Such an improvement may not only reduce the need for some types of repeat surgery but also open up the possibility of placing implants in middle-aged or younger patients when needed—a practice now uncommon because of the implants' relatively short service life. Oak Ridge is now working with the University of Alabama to win FDA approval of nitrogen-treated hip joints.

In a related development, hip implants processed with tin ions exhibit a thousandfold improvement in durability, according to Harwell researcher Geof Dearnaley. There is a possibility, though, that these implants could release toxic levels of tin in the body.

Harwell researchers are studying another novel application of ion-beam processing: the implantation of low levels of radioisotopes in chemical plant piping to monitor wear rates in inaccessible sites. In this method, called Thin-Layer Activation, cobalt-60 or some other isotope is injected a few angstroms below the surface of the inner diameter of the pipe (an angstrom is one ten-billionth of a meter). As the pipe's inner surface wears away, there is a steady increase in detectable downstream radioactivity. When the isotope concentration reaches a predetermined level, plant operators know the extent of the wear and can schedule maintenance accordingly.

Harwell claims that the amount of radioactivity in Thin-Layer Activation is about the same as that encountered in the old luminescent watch dials. The method has been tested in nitric and sulfuric acid plants owned by ICI, the giant British chemical firm. The results have been so encouraging that Harwell is now reportedly selling the process in Britain and in the U.S.

Longer bearing life. Ion-beam processing may also be enlisted to harden bearings, and the raceways that hold them, in high-stress settings such as jet turbine engines. The U.S. Naval Research Laboratory (NRL) in Washington, D.C., has been developing such applications for several years, and in 1984 gave Spire a three-year $800,000 contract to complete design work on a production-scale ion beam machine.

Earlier NRL research indicated that the saltwater environment in which Navy aircraft operate often leads to pitting, corrosion, and dramatically shortened bearing life. Because the turbine bearings cost about $2500 apiece, they are an ideal target for ion implantation. It is estimated that the useful life of bearings made of AISI M50, 52100, or 440C steels (all low-alloy steels commonly used for this application) increases by a factor of 2.5 when the bearings are implanted with ions of chromium, molybdenum, boron, or a combination of these elements.

In recent Spire experiments where titanium and/or carbon was implanted in bearing fixtures made of 52100 steel, wear rates were not only lower, says Sioshansi, but also more uniform throughout the assembly. (Since many bearing fixtures comprise dozens of individual parts, the failure of one could destroy the entire fixture; evening out wear properties could therefore extend the effective lifetime.)

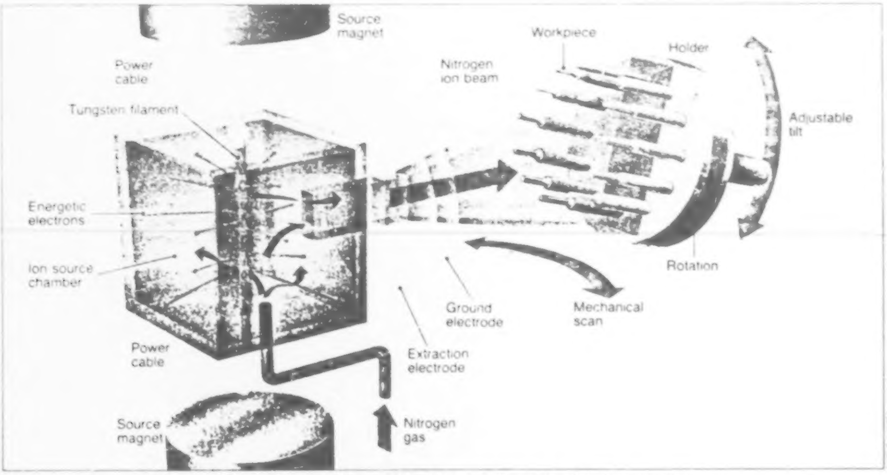
A host of other specialized metal parts have been successfully treated with ion beams, usually in applications where hardness, toughness, or resistance to erosion and corrosion are a plus. Zymet (Danvers, Mass.), for example, has nitrided cobalt-cemented tungsten carbide drills that are used to cut holes in printed circuit boards. Fatigue resistance was greatly improved, says Zymet technical director James Hirvonen, and the drills caused less smearing of melted polymer in the hole. If the latter benefit stands up during production tests, it will obviate a washing step to remove such debris.

Most significant, the drill's faster and cleaner cutting characteristics dropped its operating temperature from about 180° to 80° C. Similar results have been obtained with dies, punches, and dental drills and burrs (which could make trips to the dentist much less painful).

Nitrogen is not the only implant that imparts beneficial properties to metal tools. Spire's Sioshansi reports that spinnerets (nozzles used to extrude glass or organic polymer fibers) made of cobalt superalloy or chrome carbide have been treated with silicon, titanium, boron, and other ions. The integrity of the extrusion holes is enhanced, and oxidation is reduced.

Spire has also substantially reduced corrosion in the ink-spraying nozzles in high-speed electronic printers by using a chromium implant. "The life of the tool can be greatly improved," says Sioshansi, "and ion implantation accounts for just a fraction of its manufacturing cost."

Ion-beam mixing. Even as the first commercial applications of ion-beam processing appear, new approaches to the technology are being explored.



Nitrogen ions are implanted in metalworking punches on the adjustable workpiece holder at right. If metal ions are to be implanted instead, a compound containing the metal is vaporized inside the ion source chamber.

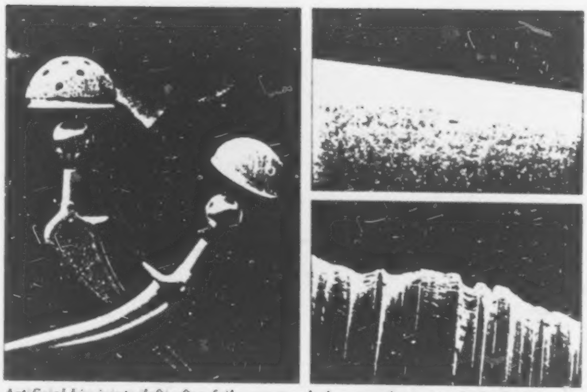
Chief among these is ion-beam mixing, in which a beam is projected onto a substrate during or after other deposition processes, such as sputtering, chemical-vapor deposition, or even conventional plating. The purpose is to "stitch" the plated layer into the substrate, preventing the plating from peeling off. Generally, high ion-beam energies are necessary. While many applications require only 100,000 electron volts, one company working in this field—Universal Energy Systems (Dayton, Ohio)—is using a 6.8-million-electron-volt (MeV) beam generator.

Such high beam energies, explains Universal chief scientist Peter Pronko, push atoms of the plating into the substrate and, through a recoil action, mix substrate atoms into the plating. Meanwhile the ion that is causing all this motion mixes with both layers. In some applications, the end result is a durable, glassy, amorphous surface.

Working under a grant from the Department of Energy, Universal is developing coatings for the turbine blades of generators that might be designed to use coal or other abrasive fuels. A layer of titanium and another of nickel are laid down; an ion beam then intermixes the two and bonds them to the substrate. Preliminary results show a doubling of corrosion resistance. Work under another recent contract, from the National Science Foundation, will examine the production of high-performance laser mirrors by "cementing" reflective metal coatings onto glass.

It is also possible to obtain the opposite effect—crystal formation in the plated layer—by changing the parameters of the implantation. According to experiments at the Pacific Northwest Laboratory (Richland, Wash.), high-energy (5-MeV) beams of nitrogen cause such crystallization in coatings of molybdenum-nickel and other alloys. The effect is thought to stem from the rapid dislocation of atoms bombarded by the ions; in the ensuing high temperature, crystal lattice positions open up, atoms move about, and fine crystals have a momentary chance to form before the coating cools. Other research suggests that extremely hard diamondlike crystals of carbon or boron nitride can be formed when those chemicals are ionized in a plasma and then accelerated in a beam onto a substrate.

Practical applications of this technique have yet to be developed, however. "Forming these hard crystals is a new ball game for ion implantation," says Spire's Sioshansi. "We have successfully worked with low-energy, 500-eV beams of boron and nitrogen to form cubic boron nitride crystals. But much remains to be learned about the technique."



Artificial hip joints (left) often fail prematurely because of corrosive body fluids, and thus are prime candidates for ion implantation. The microphotos at right were made after corrosive wear tests of implanted (top) and nonimplanted (bottom) alloy samples. (Left photo courtesy of Zimmer, Inc. Scanning electron micrographs courtesy of Oak Ridge National Laboratory/Univ. of Alabama at Birmingham.)

Ceramics and plastics. Still in the basic research phase is the use of ion beams on ceramics (other than semiconductors) and plastics. At Oak Ridge, for example, facility director William Appleton and his staff are working on improving the ductility of brittle ceramics by ion implantation. Other work at the same lab—on alumina (aluminum oxide) doped with chromium, zirconium, or titanium—demonstrates increases of up to 35% in surface hardness.

An amorphous crystalline structure can be obtained by altering the implantation conditions. In this case the ceramic surface is not as hard but is much more resistant to fracture. Interestingly, tests at elevated temperatures showed that some of the fracture resistance is lost as chromium becomes incorporated into the aluminum lattice. The result is an alumina/chromium oxide solution that resembles plain alumina. (Implanted zirconium oxide, on the other hand, is insoluble in alumina, and the structure retains its properties above 1600°C.)

Ion-beam mixing has been utilized at Oak Ridge to form metallic glasses, the amorphous metal/semiconductor mixtures that other companies—notably Allied in Morristown, N.J.—have developed through extremely high quenching rates (a method known by the unglamorous name of splat quenching). But it is still uncertain how these metallic glasses might be commercialized. Those now being produced by splat quenching are being tested in motor winding parts, transformers, data storage tape, and other applications in which their unique combination of magnetic and electrical properties might be useful.

In Oak Ridge's work, gold and germanium were vapor-deposited on alumina, then subjected to a xenon ion beam, which thoroughly mixed the gold and germanium. Metallic glasses of platinum/silicon and gold/silicon have also been formed, and Appleton and his coworkers have shown that a wide range of metal/semiconductor proportions can be generated.

Meanwhile investigators at MIT's Center for Materials Science and Engineering are trying to enhance the electrical conductivity of polymers such as polyacetylene by bombarding them with ionized conducting metals. The program is still in its early stages, according to researcher Mildred Dresselhaus, and results so far are highly tentative.

Polyacetylene is one of several polymers that researchers have discovered can be made highly conductive (most polymers are natural insulators). Although these plastics are still beset by high cost, flimsy mechanical properties, and chemical instability, they have been proposed for a broad range of applications, from rechargeable batteries to replacements for conventional metal wires.

Novel workstations. Besides the actual ion implantation process, research is being aimed at the design of workstations, the devices that hold the target substrate and make economical throughput rates possible. Since ion-beam processing is a "line-of-sight" pro-

How nitrogen implantation improves durability

Application	Material	Lifetime increase, other benefits
Scoring die for aluminum lids	D2 tool steel	3X
Copper rod finishing tools	H-13 steel	Improved surface; negligible wear after 3X normal lifetime
Paper slitters	1.6% Cr, 1% C-steel	2X
Punches for acetate sheet	Cr-plated steel	Improved product
Tool inserts	4% Ni, 1% Cr steel	Reduced tool corrosion by 3X
Fuel injectors & metering pumps	Tool steel	More than 100X in engine tests
Precision punches for electronic parts	Tungsten carbide, cobalt-cemented	More than 2X
Injection molding nozzles	Tool steels and Cr-plated steel	4–6X
Dies for copper rods & steel wire	Tungsten carbide, cobalt-cemented	3–5X; better surface finish

cess, the workpiece must be moved about in a steady, controlled manner during exposure for a uniform bombardment. And because implantation occurs in a vacuum, bombarded materials are not subject to convective cooling; temperatures can rise high enough (500°C and higher) to damage some workstation materials.

New methods use a combination of motors to move the workstation (and/or the ion source) horizontally or vertically, or to rotate the station about one of its axes. The heat that is generated during bombardment is carried away by heat-sink materials that form the surface on which the parts are placed. Both workstation movement and heat transfer efficiency affect the number of workpieces and the quality of the implantation.

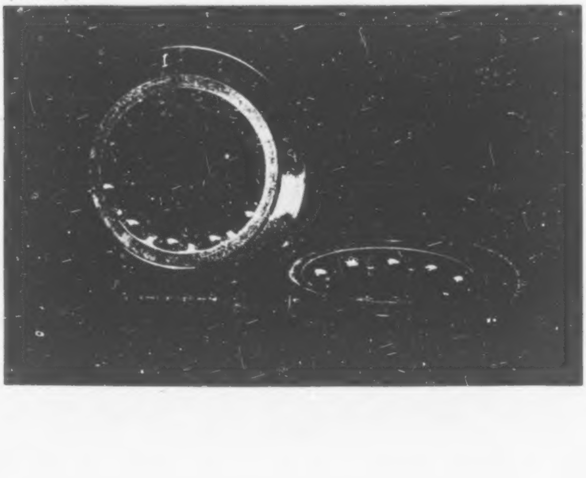
The NRL contract went to Spire largely because the firm had designed an innovative workstation and developed a method of spreading the ion beam with a quadrupole magnet, both of which prevent excessive temperatures in the workpieces. The station uses a soft thermally conductive plastic base covered with a thin nickel sheet. The ball bearing substrates are held in place by being pushed into the ductile metal sheet; the plastic conducts heat from the workpieces, keeping their temperature below 200°C during exposure. (Above that temperature, the steels used in the bearings lose hardness because of annealing effects.)

"In general it is difficult to adequately cool bearing spheres, because of their single-point contact with a surface," notes Spire's Sioshansi. "This design not only increases the area of surface contact but keeps the ball from picking up a film from the plastic," which would interfere with ion implantation.

A radically different implantation technique has been proposed by Mission Research, a small Albuquerque contract research firm. According to company president Richard Adler, Mission is developing a prototype for a pulsed ion-beam generator, which uses a thyratron (a combination of magnetic and electric field switchers) to generate up to 100 high-current pulses per second.

Normally, the high current Adler would like to use—up to 20 milliamperes, versus the usual 5 milliamperes—would cause arcing at the ion source, shutting down the machine. But with the pulsing, a rod of the material to be implanted can be used as an ion source, in much the same way as an arc welder sputters metal into a weld by an electrical current. Titanium, copper, and molybdenum ion beams have been generated; in some cases, a higher ion state (+2 or more, rather than the usual +1) was obtained, thus imparting twice the energy to the ions.

The untreated bearing (right) is badly corroded. Though subjected to similar conditions, the bearing implanted with chromium ions shows little wear. (Photo courtesy of Spire Corp.)



Adler notes that the method could be much less expensive than conventional ion-beam designs, since the use of a solid ion source dispenses with the usual requirement of first converting the material to a vaporizable form. His estimates of implantation costs, in fact, run as low as 1¢ per square centimeter of surface treated; other companies' estimates range from about 15¢ to $1 per square centimeter. Adler concedes that it may be difficult to achieve high ion purities, however, unless the rods themselves are exceptionally pure. Test results from a Department of Energy grant should be ready by mid-1985.

The many directions that recent ion-beam processing is taking—gas into metal, metal into ceramic, ions into electrically neutral polymers—seem to testify to the technology's emerging versatility. Proponents are convinced that new applications and equipment will soon make the technique commonplace.

"Even with the rapid progress of the past few years, this method is not yet being widely exploited," says Oak Ridge's Appleton. "But we think that virtually any material in use today has some property that can be improved with ion-beam processing." ☐

Nicholas Basta, trained as a chemical engineer, is a New York–based technology and business journalist.

For further information see **RESOURCES** *on page 77.*

PANEL 2: DISCUSSION

Mr. **Mineta**. Let me first yield to our fine gentleman from Illinois, Mr. Fawell, to start the questions.

Mr. **Fawell**. Dr. Schriesheim, you have mentioned some of the specifics which occur in regard to Argonne, something like 1,300 employees being laid off and 750 of that being, apparently, scientific personnel in the loss of the integral fast reactor. Are there other specifics—and then also, I'd like to have you comment on your statement that the very viability of the institution is threatened, and why you would reach that conclusion.

Dr. **Schriesheim**. In terms of the viability of the institution, there are some 4,000 total employees in the Laboratory; 3,300 are in Illinois and some 700 in Idaho. The 1,300 is almost entirely concentrated at the Laboratory in Illinois, so that would be 1,300 people out of some 3,300 people. And as you point out, there are about 750 scientists and engineers out of a total there of perhaps 1,300 or 1,400 scientists and engineers.

The intrinsic fabric of the Laboratory, which is so dependent, as I point out and the two gentlemen on my right and left point out, the interdisciplinary nature of the Laboratory, the relationship of one program to another would be adversely affected, could not but help but be adversely affected by that number, the layoff of that number.

I would point out that the shops, analytical facilities, the computing facilities, all of these are supported by the programs cojointly, all of them together support those facilities. When there is such a large decrement these facilities become extremely expensive facilities for the rest of the Laboratory to support; to some extent they become superfluous, so there's no way that layoffs of that magnitude cannot affect what is essentially a laboratory in which one discipline depends upon the next discipline. The lab is not a group of departments connected together by a steam plant. It is an institution, and that is one reason why I felt called upon to mention that today, because this committee, the parent committee, has responsibilities for these labs as institutions. It's difficult to find a place where that institutional responsibility resides.

Mr. **Fawell**. Mr. Chairman, may I inquire—I assume there's a vote now being taken?

Mr. **Mineta**. There is a vote, and we're still under the first bell so I would imagine we have maybe about 12 minutes. Do you want to recess for the time being and then come back and pick up on your questioning at that point? That would be fine with me. I have no problems dealing with that.

That being the case, then, we'll go ahead and recess at this time since there is a call to the House for a recorded vote, and we'll reconvene in about 15 minutes.

[Recess taken.]

Mr. **Fuqua**. If we could resume the hearing and the witnesses would take their seats.

Dr. Postma, how is your budget projected compared with the current year budget that you're under right now? How does the fiscal year 1986 compare with the fiscal year 1985 budget, particularly on the basic research?

Dr. Postma. In the basic research area we will be up by 1 percent, which means down by 4 percent in terms of the number of people involved, so we will be reducing our staff in that area by approximately 4 percent.

Mr. Fuqua. Four percent staff reduction?

Dr. Postma. That's assuming, of course, as I mentioned earlier in my testimony, that the congressionally mandated projects which were not included in the administration's budget do not sort of come off the top. If they are in addition to the budget, that would make very little additional impact. However, if they come out of the budget we would presume there will be an overall 12.8 percent decline in our staff as a result of the congressionally mandated——

Mr. Fuqua. That means layoffs?

Dr. Postma. Yes. Reductions in staff, yes.

Mr. Fuqua. Have you begun that process?

Dr. Postma. We have let our staff know that there are some difficult times ahead but, as you know, if we proceed to do things upon the administration's budget without taking into consideration the congressional concerns, that is not a very wise thing for us to do, so we're holding off as long as possible, waiting to get the intent of Congress into our decision.

Mr. Fuqua. Dr. Schriesheim, you are looking at a reduction of about 20 percent in your operating budget?

Dr. Schriesheim. Somewhat over 20 percent; that is correct.

Mr. Fuqua. And is that all as a result of the decrease in the breeder program?

Dr. Schriesheim. A little over 50 percent of that is as a result of the decrease in the breeder program. That tends to feed on itself, though, Mr. Chairman, because that cut would be so large that closeout costs would have to be taken out of programs, so that builds up a little higher than one would expect, simply looking at the dollar figures.

Mr. Fuqua. And does that impact on both of your sites?

Dr. Schriesheim. It is almost entirely at the Argonne East site in Illinois.

Mr. Fuqua. You will be able to stay a little bit later?

Dr. Schriesheim. Certainly.

Mr. Fuqua. I understand Mr. Fawell may have some questions; he has not arrived back yet, and we may, at the tail end, if you can—and I understand Mr. Postma must leave, I believe.

Well, we will conclude this part of the hearing and excuse you, and if you can stick around, we may have some other questions.

Dr. Postma. Thank you very much, Mr. Chairman.

[Questions and answers for the record follow:]

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439 Telephone 312/972-3872

March 21, 1985

RECEIVED
[illegible]
COMMITTEE ON SCIENCE
AND TECHNOLOGY

The Honorable Don Fuqua
U.S. House of Representatives
2269 Rayburn House Office Building
Washington, D.C. 20515

Dear Representative Fuqua:

I am transmitting my answers to the questions posed in your letter to me dated March 5, 1985. It was an honor to provide testimony before the Subcommittee on Energy Development and Applications, and I am pleased to provide the additional information.

Sincerely,

Alan Schriesheim
Director

AS:gb

U.S. Department of Energy The University of Chicago

ANSWERS TO

Subcommittee on Energy Development and Applications

QUESTIONS
FY 1986 DOE Authorization for Basic Research
February 28, 1985

Argonne National Laboratory

Dr. Alan Schriesheim

1. What steps is Argonne National Laboratory (ANL) taking to participate in truly cooperative and collaborative research projects with its regional university communities?

Argonne has an active continuing program of collaboration with the university community. This cooperation and collaboration occurs on several levels; including collaboration involving individual scientists, research by university scientists and engineers at major ANL user facilities, and formal agreements for joint development of new scientific ventures.

A large number of the scientific publications involving ANL authors also include joint authors from universities. Last year, nearly half of the publications from our Physics Division had university co-authors, as well as 40% of the Chemistry publications. Similar publication statistics apply to the other scientific divisions. Our user facilities provide access for hundreds of academic scientists each year to unique opportunities for research. More than 2000 facility members and graduate students participate in ANL activities each year. Typically, each year, ANL has provided appointments for nearly 100 post-doctoral scientists, about 180 graduate students, and 150 faculty members. Many ANL staff members hold joint appointments with universities locally and internationally.

A few typical examples which are illustrative of the active cooperation and collaborative projects are summarized below:

The development of a gamma-ray facility, an instrumentation development at the Argonne Tandem-Linear Accelerator System (ATLAS), is being carried out in partnership with Notre Dame University. In addition ATLAS technology is being shared with several other institutions, including Kansas State University and Florida State University.

We are involved in a neutrino-oscillation search at the LAMPF accelerator at Los Alamos in collaboration with several university groups. Our contribution involves a major responsibility in the construction of a large and sophisticated neutrino detector for the experiment.

We are participating in a collaboration with the University of Minnesota, Tufts University, and Oxford University in Great Britain on an experiment which looks for nucleon decay. This involves a large sophisticated detector which is operating deep in the Sudan mine in Minnesota.

An important initiative being developed at this time involves a formal arrangement with two local universities, Northern Illinois University and The University of Chicago, and industry to jointly establish a plant biotechnology research program. This program will explore the basic research required to apply the new advances in biotechnology to a spectrum of opportunities in biomass and crop production.

The Laboratory is actively searching for ways to enhance its interactions with the academic community. We believe this can provide educational opportunities to graduate students and unique research opportunities to faculty members. At the same time the government profits by obtaining an optimum return on its research investment.

2. What steps is ANL taking to participate in truly cooperative and collaborative research projects with its regional industrial communities?

Argonne has undertaken major efforts to involve the industrial community in its programs. Industrial participation in some of the more applied areas provides useful guidance and helps the Laboratory to set priorities. Industrial participants also are involved in basic research at the Laboratory's user facilities.

A recent example of our effort includes the steel initiative discussed in question 6. Another related activity involves the off-road machinery industry, largely centered in the mid-west. ANL is exploring with several industrial firms (e.g. Caterpillar, Deere, and others) the opportunities for joint research efforts.

The Laboratory has sponsored workshops on such subjects as Thermomechanical Behavior of Refractories, Hard Coatings for Tribological Systems, Electrochemical Industrial Associates, and others. Many of the contacts result in scientific work sponsored by the industrial firms. ANL's efforts to involve the industrial community in the joint research programs in biotechnology is discussed in the response to question 1.

We constantly are searching for ways to improve our nation's competitive posture and to increase productivity through transfer of the knowledge gained from our research. To this end we are forming a joint Argonne/University of Chicago Development Corporation which will encourage and aid the development of intellectual property (defined as patents, processes, capabilities for innovation, invention reports, computer software, etc.) developed at ANL and The University of Chicago. The Corporation will be not-for-profit and will commercialize new technologies by licensing patents for royalties and developing privately-funded, joint ventures for capitalization. The Corporation will be separate from ANL and ANL's contractor (The University of Chicago), with overview by a board of directors. A search for appropriate leadership and staff is presently underway. A portfolio of patents and other intellectual properties has been prepared for evaluation and use by the Corporation, which is expected to approach self-sufficient status after three years of operation.

3. You note that in FY 1986 Argonne is threatened with a reduction of more than 20% in its present operating budget. Please present a program by program comparison of ANL's actual and estimated funding for FY 1984, FY 1985 and FY 1986.

The detailed program by program comparison of ANL's actual and estimated funding is presented on the attached table. It should be noted that the table addressed DOE funding only, and excludes other sources of revenue, which also are expected to be reduced in FY 86 compared with the present year.

4. How will the reduction in Argonne's budget impact the Argonne-East and the Argonne-West sites, respectively? What level of layoffs are you facing at each site? Why is Argonne-East faced with a disproportionate share of the budget reductions and layoffs?

What level of layoffs will affect each site?

The layoffs are expected to come entirely at the Illinois site. The Argonne-Idaho budget at worst is level, and it may in fact project a slight increase. The projected personnel reduction at the Illinois site is 1335, mostly associated with the nuclear program. However, other programs, including fossil energy and conservation will be affected as well. The relative effects are related to the budget changes shown on the table in response to question 3.

Why is ANL-E faced with a disproportionate share of the layoffs?

We, of course, cannot speak for the department. It appears however, that the Department made a policy decision to adequately fund the large breeder test facilities on the ANL-W site (about $40M) and at the Hanford site (about twice the ANL-W amount). The large steam generator test facility at ETEC California is also funded at about a $15M level. When the sum of test facility funding is added to the approximate $20M funding for design studies at industrial contractors, there is little left for actual technology development in the total liquid metal cooled reactor budget at $200M. Because the ANL-E role is technology development -- it is, in fact, the natural center for development of the technology for the entire nuclear portion of the liquid metal reactor system -- it is caught in the vise caused by the apparent DOE policy decision.

Our very strongly-held belief is that a decision to maintain test facility operation and let the R&D personnel and capability go, is simply wrong. Little that is new and promising can be developed in this situation, and in fact the facilities themselves, which exist to test technology development, cannot be expected to survive for long in its absence. We believe that the unintended result must inevitably be to bring the entire program to a close out position probably sooner than later. This is in no ones interest, and certainly not in the national interest, as the liquid metal reactor remains today by far the most promising avenue to long-term electrical supply, and potentially the most promising immediate next-generation reactor type as well. But it does need improvement over the present breeder concept, and avenues to such improvements have been identified. But they do need further development, which will occur in the future that the budget which we propose would mandate.

5. What is the status of ANL's long-range plan?

ANL prepares a five-year Institutional Plan each year and submits it for approval by the Department of Energy. The most recent plan was issued in November, 1984, and received DOE's approval. In addition to this formal planning activity, which is coordinated with DOE, the Laboratory has its own internal effort. An example of this effort is the Report of the ad hoc Committee on the Future of Argonne prepared by the University of Chicago Board of Governors for Argonne National Laboratory, which is attached. This report has been discussed with the management of the Department of Energy and others. It provides a basis for initiatives being proposed by the Laboratory. Of course, the effect of these drastic budget changes would be to completely invalidate the projections made in the approved Institutional Plan.

6. (SUBMITTED BY MR. WALGREN) We understand that ANL recently entered into a joint research venture with U. S. Steel and Bethlehem Steel Company, and that the venture is focused on developing a direct steel-making casting process.

   a. Please tell us about the origins of this project. Did it originate with ANL, or were you approached by the steel industry?

   b. As an energy research laboratory, what kind of capability do you bring to researching steel-making processes? Do you have the mix of skills on hand for this project?

   c. What share of the $30 million cost of this project will ANL bear? If successful, will you recoup your cost?

   d. Will the results of this project be available to all of the U.S. steel industry?

   e. Given that Allegheny-Ludlum Corporation, a specialty steel maker, and Nucor, a mini-mill operation, are either producing direct cast thin flat-rolled products already, or are engaged in developing these processes on their own, what justification is there for government-funded research efforts in this area?

f. What kind of effort or support, apart from cost-sharing, are you getting from the steel industry?

g. What estimates can you provide for both the energy conservation to be achieved by this project and the effect on costs of steel-making?

The project to scale up the Haezlett continuous casting process, to which Mr. Walgren refers, is a joint venture between the U.S. Department of Energy and two major steel manufacturers, U.S. Steel and Bethlehem Steel, and is not a part of the proposed Steel Industry/Federal Laboratory Initiative. It does not involve Argonne National Laboratory at this time.

The Steel Industry/Federal Laboratory Initiative is a collaborative research program of a highly exploratory nature directed at the development of selected "leapfrog" technology which has the potential for dramatically enhancing the competitive position of the U.S. steel industry in the 1990's and beyond. This initiative originated with the President's Commission on Industrial Competitiveness and emerged as the joint project of Dr. George Keyworth, the President's Science Advisor, who chairs this Commission, and Mr. Howard "Pete" Love, Chief Executive Officer of National Steel and a member of the Commission. Further, this initiative represents an important step in implementation of the recommendations contained in the Packard Report regarding the role of federal laboratories.

The Steel Industry/Federal Laboratory Initiative has been guided by a steering committee dominated by vice presidents for research and senior scientists and engineers from the steel industry with participation from Argonne, Oak Ridge, and the National Bureau of Standards, and ex-officio representatives of Dr. Keyworth and of DOE. The research agenda which emerged from this intensive study by the steering committee and four separate tasks groups has been outlined in the testimony by Dr. James Leonard of Bethlehem Steel.

As Dr. Leonard noted, the steel industry will contribute approximately $1.5 million in each of the first two fiscal years with the federal government through the U.S. Department of Energy providing $10 million per year. In addition, the industry will contribute significant input from senior management and will make available to all participants certain proprietary technologies. Such a cost-sharing formula would appear quite reasonable given the highly exploratory nature of the program and the current financial situation of the U.S. steel industry. The results of the project will be available to all of the U.S. steel industry through the American Iron and Steel Institute (AISI). AISI has reprogrammed a substantial portion of its annual budget to partially reimburse steel industry representatives that contribute scientific and engineering manpower and/or research facilities to the collaborative effort. The industry funding will go to providing the industry input to the research and, implicitly, the follow-up technology transfer.

The proposed Steel Industry/Federal Laboratory Initiative has the potential for a reduction by 1/3 of the high energy input required for steelmaking by today's technologies and an attendant reduction in capital and operating costs trageted at 30% and 50% respectively, reflecting the inherent modularity, flexibility, product control and energy savings associated with the exploratory technologies to be addressed.

7. What would you like to accomplish during your tenure as Director of ANL? Where would you like the Laboratory to be 10 years from now?

First I must begin by stating that a successful laboratory director should be in the leadership role long enough to initiate and implement policy. Short term heads of R&D organizations are apt to do more harm than good. In the case of Argonne, during the last 20 years the laboratory has had seven directors including two in an acting capacity.

What I would like to accomplish during my ten years is ambitious and may be summed up as one goal with a number of strategies for achieving that goal.

GOAL

Solidify Argonne's role as a world class research and development organization with major thrust in the energy-sector and having high impact in both the academic and industrial communities, with major emphasis on the midwest.

Strategies

1. Programmatic

Stabilize the reactor programs, with the IFR as the centerpiece.

Argonne is the nation's leading center for nuclear reactor research and development. Last year the Nuclear Energy program of DOE provided 40% of the financial support for the laboratory. Long term predictable funding is essential for such a significant segment of our effort. The Integral Fast Reactor (IFR) is an outgrowth of this program, and promises an inherently safe breeder reactor which can result in reliable and cost-effective operation.

Strengthen and provide increased focus to the materials science effort.

Materials performance is recognized as the principal barrier to the development of more efficient and reliable energy technologies. Materials advances are almost always the key to development of more efficient and reliable processes and products. Improved alloys and ceramics are currently finding their way into a wide variety of high-temperature, energy-saving applications, including structural ceramics for recuperators and engine components, and composite materials for high-strength applications. For the future we see excellent potential for materials developments such as wider classes of transformation-toughened ceramics, electrically-conducting ceramics, new alloys tailored for corrosion/erosion resistance and high-temperature applications, and a whole array of new coatings technologies for improved friction and wear resistance.

- Develop new national major facilities and thrusts which mesh into ANL's areas of strength.

In order to provide researchers in this country with a new generation instrument for pursuit of condensed matter research, ANL has developed a pulsed-neutron research facility. The Intense Pulsed Neutron Source (IPNS) consists of a linear accelerator injecting 50 MeV protons into a rapid-cycling proton synchrotron which increases the proton energy to a maximum of 500 MeV. These protons are then used to bombard heavy element targets to produce slow neutrons at 4×10^{14} n/cm^2 sec peak flux for neutron scattering experiments. IPNS is established as a national user facility to serve the needs of universities, industries, and national laboratories.

We are proposing a long-term upgrade of the neutron research capabilities at IPNS. The goal of this upgraded system, the Argonne Super Pulsed Spallation Neutron Source (ASPUN) project, is to provide a facility that can deliver pulsed neutron fluxes exceeding 1×10^{17} neutron/cm^2-sec in few-hundred nanosecond bursts at a repetition rate around 50 Hz.

The scientific progress and the technological promise afforded by synchrotron sources, coupled with the dramatic intensity and brightness increases obtainable from insertion devices, have led to a call within the scientific community for a higher energy source, to exploit the virtues of synchrotron radiation and extend them in intensity, brightness, and energy.

A group of scientists from the Midwest is determining the interest in having a 6-GeV synchrotron source located in the region. This group includes, users of Tantalus, SSRL, CHESS, NSLS, and DCI; many of the members of one NSLS PRT and participants in another; and developers of beam lines at Aladdin. Enthusiasm for developing a proposal for a Midwestern source is high. A proposal has been prepared at ANL by scientists from ANL, Iowa State University, Northern Illinois University, Purdue University, the University of Chicago, University of Illinois - Urbana, University of Minnesota, University of Missouri - Columbia, and the University of Wisconsin - Madison.

The opportunity exists for a high energy source to supplement the VUV/soft X-ray Aladdin source at the University of Wisconsin-Madison. In addition, this source would also complement the Argonne Intense Pulsed Neutron Source (IPNS). Thus, interactions and collaborations exploiting inelastic neutron and photon scattering would be strongly enhanced. The fact that these three sources would be located in an easily accessible part of the country is important in view of the extensive user program that each of the facilities maintains or will maintain.

- Become the center of tribology research

  Recent studies have shown that approximately 12% of the total U.S. energy consumption per year, or approximately 20-billion dollars per year, can potentially be saved by the improved tribological performance of machinery and industrial processes. The solutions to tribological problems typically require the collaboration of scientists and engineers of various disciplines, such as materials sciences, physics, chemistry and mechanical engineering. In recognition of our outstanding record of research accomplishments in the basic surface sciences underlying this field, and our extensive experience in operating user facilities for industry, universities, and other scientific organizations, the Department of Energy has designated ANL as its lead center for tribology research and assigned us responsibility for management of the National Tribology R&D program.

- Expand the advanced computing research program

  Computational science seems ready to take its place as the third scientific methodology, alongside theory and experimentation. New machines yield unprecedented performance while high performance automated reasoning techniques open up new application areas. These developments result from advances in computer architectures and non-numerical techniques. Far from leading to a steady state, these advances spur demands for increased performance that can only be achieved through the use of extensive parallelism in computer architectures. The complexity of the resulting systems poses formidable challenges: we must not only find ways to organize and express computations so that high performance is obtained on new architectures, but also discover how to avoid repeating the process for each new design.

  Among the projects that should be undertaken are: a) research on portable yet high-performance algorithms and software, especially for automated reasoning, logic programming, and numerical tasks; b) creation of programming tools and environments that promote efficient and portable programming for advanced computers; even the fastest hardware is of little use if programming environments are inadequate; and c) development of methodologies for assessing advanced architectures that enable reliable prediction and measurement of their performance for given applications.

- Enhance the chemistry research program

  We intend to follow up the recommendations of George Pimentel's report on chemistry research. In his testimony, Dr. Pimentel identified chemistry as a science having a major impact on our society, but one which is underfunded. He identified several areas in which DOE should undertake major initiatives. We strongly agree with his analysis and intend to develop expanded initiatives in areas of particular importance to ANL based on our strengths. Studies in chemical reactivity, catalysis, and electron charge transfer, which is the basic principle for solar energy conversion (including photosynthesis) and much of the basic chemistry of life processes will be emphasized.

- Develop a program in biotechnology, with emphasis on plant biotechnology. Our efforts in this area are discussed in the answer to question 1.
- Enhance technology transfer and develop programs based on existing strengths that will lead to improvement in US industrial competitiveness and strengthen a broad range of US capabilities; for example, space nuclear power, and high temperature superconductors.
- Enhance existing and generate new outreach activities to the academic and industrial sectors. A few of the activities which illustrate our approach are discussed in the answer to questions 1, 2, and 6.

2. Operational

- Run an efficient, cost-effective organization.
- Bring in the best possible people, identify and nurture our highly trained and skilled scientists and managers; spot early talent and nurture it. Define an optimal system for doing so.
- Identify key young people at universities and provide opportunities for them at the laboratory.
- Implement managerial strategies that provide maximum utilization of the organization's strengths in an interdisciplinary mode without adversely affecting the organizational units.

At the end of ten years with the above goal and strategies firmly in place, I believe that ANL will be an important factor in the new use of science and technology for the nation, with a major emphasis on the midwest.

8. We sent you a copy of the Committee's Science Policy Task Force's Report, An Agenda for a Study of U.S. Science Policy. Would you like to comment on the Report? What important issues concerning the government laboratories in general and your laboratory in particular do you believe should be included in the Task Force's study?

The proposed agenda for the review of American science policy by the Science and Technology Committee is a comprehensive one. The examination of the future role and functions of the government laboratories, including national laboratories such as Argonne, is timely and the questions identified by the Committee are critical.

In addition, the Committee may wish to consider issues related specifically to increased laboratory-university-industry cooperation. This is among the topics to be addressed by Research Roundtable Working Group Three of the National Academy of Sciences. In connection with that activity, I recently asked the directors of the DOE multiprogram laboratories for their views, and they identified the following issues.

University-related issues

1. What are the possible long term effects on universities if their involvement in alliances with laboratories and/or industry becomes excessive?

2. What are the factors that have led to success in cooperation between universities and certain laboratories? Can they be applied to other alliances?

3. What are the institutional barriers hindering expansion of the role of the laboratories as loci for graduate thesis research?

Legal and Policy Issues

4. If national laboratories expand further their alliances with industry, or with groups of industries, will these alliances run the rusk of violating anti-trust legislation?

5. What are the policies of the Federal agencies regarding implementation of the recent changes in patent law?

6. Can tax incentives be developed to encourage industry to enter into cooperative research programs with Federal labs? With Federal laboratory-university consortia?

7. Are the laboratories precluded from generating projects with small businesses under the terms of the Small Business Innovation Act?

8. Can Federal procurement policies be made more flexible to allow increased use of judgment by laboratories in selecting industrial partners in development projects?

Funding Issues

9. Can U.S. industrial funding practices be changed so that industry will absorb part of the R&D costs in transfer of technology from laboratories?

10. Can continuity of Federal funding for R&D be improved?

Technology Transfer Issues

11. Can Federal laboratories be charged to bridge the gap between the labs and the commercial market? And be funded to develop feasible technologies?

12. Are additional and different staff needed at the laboratories to aid in technology transfer? What other mechanisms can be devised to aid the process?

13. How can a technology transfer network be developed to inform potential users of the expertise existing in Federal labs?

The University of Chicago
Board of Governors
for
Argonne National Laboratory

Report of the ad hoc Committee on Future of Argonne: Summary

W. Dale Compton, Co-Chairman
Stuart A. Rice, Co-Chairman
Theodore L. Brown
Walter E. Massey
Frank W. Putnam
George A. Russell
Monroe Sadler
Alan Schriesheim

August 1984

In establishing the ad hoc Committee on Future of Argonne, Mrs. Hanna H. Gray, President of the University of Chicago and Chairman of the Board of Governors of Argonne National Laboratory, charged the members "to work with Laboratory management and the University of Chicago in recommending to the Board and the Laboratory a long-range strategic plan" for Argonne. She added that the "recommended plan should be consistent with the mission of the Department of Energy and national needs in research and development. It should also recognize the roles of the national laboratories vis-a-vis those of universities and industries" and it should consider the strengths and particular characteristics of Argonne as compared to other national laboratories. (The charge and committee membership appear in appendix A.)

In attempting to carry out this charge, the committee has sought to:

- o Develop a realistic statement of mission for Argonne National Laboratory;
- o Evaluate the appropriateness of the technical programs;
- o Identify Argonne's unique strengths and capabilities;
- o Develop goals, strategies, or themes under which ANL's programs can fit;
- o Outline a plan for implementation of the strategies; and
- o Identify constraints that may interfere with the implementation of the plan.

The ad hoc Committee submitted its report to Mrs. Gray on July 10, 1984. In the transmittal letter, Co-chairmen W. Dale Compton and Stuart A. Rice offered the following comments.

> The ad hoc Committee on Future of Argonne is pleased to submit for review and consideration the attached report. In considering the future of Argonne, we have been keenly aware of the commitment that The University of Chicago has made to continue to strengthen Argonne National Laboratory and to ensure that it is an outstanding center for energy-related research.
>
> During the process of our deliberations, we have examined a variety of documents that review the roles of the national laboratories of the Department of Energy, we have met with a select group of faculty of The University of Chicago, we have heard presentations by the senior staff of the Laboratory relating to current programs and their views of future opportunities and plans, and we have met informally with key national figures in the scientific community.
>
> Argonne National Laboratory has great strengths and potential. Without a doubt, its greatest asset is its many outstanding people. We trust that you and anyone who receives this report from you will recognize that it is within this context that our observations and recommendations for strengthening the Laboratory are offered.

The report was accepted by The University of Chicago Board of Governors for Argonne National Laboratory at its meeting on July 26, 1984, and the Committee was discharged.

The report summarizes the findings and recommendations of the Committee. It addresses the following principal areas of concern:

Mission of Argonne National Laboratory

Programmatic Issues

General Management Issues

Argonne-University Interactions

Argonne-University of Chicago Relationships

Argonne-Industry Interactions

Implementation

Findings and conclusions are offered in each area. The section on implementation discusses the barriers that appear to exist in achieving some of the opportunities that have been identified.

As with all long range plans, the report must be viewed as subject to change. While circumstances and opportunities may dictate changes in the specific programs that are identified, it is believed that the long-term viability of the Laboratory will be enhanced by a direct attack upon the problems that have been identified and by establishing an overall direction as is outlined in the plan.

Following is a summary listing of the recommendations contained in the report of the ad hoc Committee on Future of Argonne. The context in which they are offered and the justification for them are contained in the detailed discussion that is associated with each item in the report.

MISSION OF ARGONNE NATIONAL LABORATORY

At the request of the ad hoc Committee on Future of Argonne, the management of the Laboratory developed the mission statement set forth below. The ad hoc Committee has carefully considered it and recommends that the Board of Governors of the Laboratory and the President of the University of Chicago give their approval to the mission statement and that it be transmitted to the Department of Energy with a request that the Department concur in and support it. It will be the responsibility of the Board of Governors to ensure adherence to this mission.

Argonne's mission consists of five major elements deriving from the fundamental mission of the Department of Energy. The elements are:

- Conduct research and development for design of all types of advanced nuclear energy plants;

- Conduct basic research in the physical sciences and the energy-related life and environmental sciences;

- Perform applied research and technology in energy-related areas, including fusion and coal combustion technology;

- Develop and operate capital-intensive scientific facilities based on Argonne's special technologies and skills, for utilization in research by academic, industrial, and other scientists and engineers;

- Engage in outreach activities in the areas of technology transfer, university interactions, and education of the interested non-scientific public.

PROGRAMMATIC ISSUES

Programs

Argonne National Laboratory is clearly a leader in research and development for design and engineering of fast breeder reactors. The ad hoc Committee recommends broadening this role to include all types of nuclear reactors for generation of electrical power and especially near term to formulate a program on improved light water reactors which are of vital importance to survival of the nuclear energy industry.

While there are many other centers of excellence in the Laboratory none has gained the stature and prominence of the breeder program. The Committee believes that the stability of the Laboratory and recognition of its importance by the scientific community and by the nation would be greatly enhanced by coalescing a number of programs into a second major program. Such a program should be built primarily upon the Laboratory's existing strengths and should be sufficiently well-defined and focussed to enable Argonne to establish a highly visible leadership position. A number of possibilities are now under consideration, e.g., certain areas of materials research, artificial intelligence, biotechnology. This Committee recommends that a proposal for a second major field be fully and promptly developed for review by the Board of Governors and for discussion with the DOE.

It is recognized, however, that the Laboratory currently does not have the authority to unilaterally coalesce individual programs into a more thematic effort, to redirect efforts into new areas, or to assume a national leadership role for particular programs for which it possesses a unique capability.

It is, therefore, the recommendation of the Committee that the Laboratory and the University of Chicago develop an action plan, utilizing the Board of Governors and others who may agree with these views, for early discussions with the Secretary of Energy and the Director of the White House Office of Science and Technology Policy.

At least two elements should be considered for inclusion in this action plan. These are: first, that DOE delegate to the contractor - the University of Chicago - authority to make such programmatic changes as may be necessary to accomplish this redirection, and, second, that DOE develop a mechanism by which the Laboratory and the University can accomplish the recommendations that its contractor - the University of Chicago - will offer to it.

Argonne has a number of programs which are in various stages of evolution, are considered to be of particular interest, and could become a major new future thrust. Evolving, current programs which are being enlarged include the integral fast reactor; fusion; and advanced materials research and development, and materials R&D associated with technologies of importance, such as the advanced breeder and fusion, and other areas. Significant/major new programs under consideration for development, for which new funds must be sought include biotechnology; advanced computing research; and a midwest coal technology development institute.

Unique Facilities

The Committee recognizes the importance of unique facilities to the national scientific and technical community and it endorses Argonne's continuing development of leading-edge facilities for use by its own staff and by people from other organizations.

It is essential that future planning take full cognizance of the need and opportunities for creating and maintaining such unique national facilities. Accordingly, the Committee recommends that Laboratory management review and strengthen the process of: (1) identifying both internal and national needs for important major facilities; (2) presenting the arguments for their funding and their location at Argonne or elsewhere in the Nation; (3) planning, with the assistance of potential users, for them; and (4) implementing the new facilities.

Argonne presently operates a number of major facilities. Some of these, such as the Intense Pulsed Neutron Source (IPNS), are user-oriented while others, such as the 22 MeV electron linac (used primarily for radiation chemistry research), serve primarily the needs of the research staff of the Laboratory. Other facilities include the electron microscopy center for materials research; the Argonne Tandem-Linear Accelerator System (ATLAS); and the extensive complex of reactor program facilities at Argonne-West. In addition, planning and design efforts are underway for a 6 GeV synchrotron radiation source and the Argonne Super-Pulsed Spallation Neutron (ASPUN) Source.

GENERAL MANAGEMENT ISSUES

The Committee has found that the concerns noted by various national study groups are directly relevant to Argonne. Procedures, as required by DOE, critically limit the capability of the Laboratory's administration to alter the course of the programs or even to correct imbalances that may exist. The University of Chicago, as the contractor responsible for operating Argonne National Laboratory, also has limited authority to accomplish needed changes. An inefficient and somewhat ineffective management system has resulted. This situation can only be redressed by the Department of Energy. The urgency in doing so cannot be over-emphasized.

It is recommended that the Laboratory and the University of Chicago develop an action plan, utilizing the Board of Governors and other interested parties, for early discussion with the Secretary of Energy. These discussions must produce a plan that will address the issues raised by this Committee and groups studying the national laboratories. (Appendix B contains a discussion of multi-year funding of research and development at national laboratories.)

ARGONNE-UNIVERSITY INTERACTIONS

The Committee recommends that the Laboratory significantly expand its existing activities designed to bring about cooperation with faculty and students of area universities in research and training. The Laboratory should:

Assure that its one-of-a-kind central research facilities are available to university research persons.

Seek additional joint appointments with universities in areas where there is a strong commitment to a common research area at both institutions.

Expand and strengthen the functions of Argonne's Division of Educational Programs.

Establish a "Semester in Residence" program in particular subject matter areas, involving several scientists, all interested in a common theme.

Consider the feasibility of locating certain Laboratory facilities and/or programs on university campuses with co-management by the host institution and the Laboratory, or possibly by a consortium or association involving a number of academic institutions and the Laboratory.

Develop with DOE a procedure that allows the Laboratory to allocate resources to persons outside the Laboratory in order to bring the best scientific and technical talents to bear on energy problems.

ARGONNE-UNIVERSITY OF CHICAGO RELATIONSHIPS

As the Committee believes that the Laboratory and the University should undertake to strengthen still further the linkages between the two institutions, it recommends that the University and the Laboratory establish a joint committee to explore, develop, and recommend specific means for effectively increasing the linkage between the two institutions. It is further recommended that the University and the Laboratory establish a fund for support of the activities recommended by the committee. As a first step in accomplishing this, it is recommended that the Board of Governors establish a fund for the explicit purpose of further stimulating professional interaction between the two institutions. Additional needs for this purpose should be addressed in the normal budget processes.

ARGONNE-INDUSTRY INTERACTIONS

The Committee recommends that, by 1985, the Laboratory establish joint cooperative programs with industry in suitable areas, through steps such as the following:

> Open opportunities for the staff to spend several months working in industrial research laboratories as well as opportunities for industrial scientists to spend time at Argonne.
>
> Develop closer ties with industrial groups, e.g., IRI (Industrial Research Institute) and EPRI (Electric Power Research Institute), possibly through scheduling periodic reviews of Argonne's R&D activities.
>
> Seek opportunities for increased representation of industry on the Board of Governors, review committees and other appropriate bodies, and include people who have had business responsibility in addition to their technical background.
>
> Establish joint efforts with industrial companies that have skills and resources to assist the Laboratory in fulfilling the objectives assigned to it by the Department of Energy.

The Committee recommends that the Laboratory explore ways to increase transfer of its technology to industry.

One way in which the coupling between Argonne and the private sector may be strengthened is through the proposed Argonne Development Center (ADC). The ADC would examine the Argonne technical "portfolio" and conduct advanced development work on specific items of commercial interest, thus bridging the gap between invention and commercialization. The development function would include advanced engineering-economic analysis, early market-place testing and feedback, laboratory R&D and small scale pilot plant development. Private venture capital appears to be the appropriate funding mechanism. It is proposed that the center be constructed at or close to Argonne, and have its own director and a small staff of venture managers/entrepreneurs.

IMPLEMENTATION

The Committee agrees strongly with studies that argue for the establishment of multi-year funding for the national laboratories. These arguments should be presented to the White House Office of Science and Technology Policy, the House of Representatives Committee on Science and Technology, the Senate Committee on Energy and Natural Resources, and the Department of Energy.

The ad hoc Committee has made a number of recommendations that require action on the part of others, in particular, the Department of Energy. The Committee envisages that this should take place in the following sequence. First, concurrence and support should be obtained from DOE for the mission statement for Argonne, thus providing the Laboratory with a clear path for supporting the overall mission of DOE. Second, DOE must address the programmatic focus for Argonne. Recognizing the leadership role that Argonne currently possesses in the breeder reactor program, it is essential that a mechanism be developed to identify other leadership roles in at least one of the several program areas in which Argonne has capability. Following agreement with DOE concerning the programmatic directions that will be emphasized, it will be necessary for DOE management to take such actions as will be required to implement these themes. Since there appears to be little incentive for the individual program offices in DOE to transfer funds among them, DOE management must put in place a procedure that will allow re-programming of funds to accomplish any agreed-upon redirection.

* * * * *

Following acceptance of the report of the ad hoc Committee on Future of Argonne and discharge of the Committee, President Gray appointed an implementation group to represent the Board of Governors in presenting the report to key government officials. Membership includes W. Dale Compton and Walter E. Massey, Co-chairmen; Kenneth H. Keller; Cora B. Marrett; Monroe S. Sadler; and Alan Schriesheim.

Appendix A

Ad hoc Committee on Future of Argonne

Charge:

To work with Laboratory management and the University of Chicago in recommending to the Board and the Laboratory a long-range strategic plan for Argonne National Laboratory. The recommended plan should be consistent with the mission of the Department of Energy and national needs in research and development. It should also recognize the roles of the national laboratories vis-a-vis those of universities and industries. It should consider the strengths and particular characteristics of Argonne as compared to other national laboratories.

The committee should issue its recommendations in time for possible submission in the FY 1986 budget of the Department of Energy. Thus, the preliminary report should be ready for discussion by the Board of Governors at its meeting in April 1984.

Among the documents that the Committee on the Future of Argonne should consider are the reports of the Energy Research Advisory Board on multi-program laboratories; of the DOE Task Force of the President's Council on Cost Effectiveness; and that of the White House Science Council on the national laboratories. The strategic and institutional plans developed by Argonne should provide relevant background for the committee's work.

The membership of the Committee shall total eight, including six Board members and as ex officio members, the Laboratory Director and the Senior Deputy Laboratory Director.

Membership:

Theodore L. Brown
Vice Chancellor for Research
University of Illinois at Urbana-Champaign

W. Dale Compton, Co-chairman
Vice President - Research
Ford Motor Company

Walter E. Massey
Vice President for Research and
for Argonne National Laboratory
The University of Chicago

Frank W. Putnam
Distinguished Professor of Molecular
Biology and Biochemistry
Indiana University

Stuart A. Rice, Co-chairman
Dean, Physical Sciences Division
The University of Chicago

George A. Russell
Chancellor
University of Missouri-Kansas City

Monroe S. Sadler
Consultant

Alan Schriesheim
Director
Argonne National Laboratory

Appendix B

Background on Multi-Year Funding for Research and Development at National Laboratories

> The purpose of this paper is to raise the issue of instability and uncertainty of funding for the national laboratories and to suggest a mechanism of dealing with it by making available funds that can be spent over a period of years. One mechanism is the institution of a multi-year authorization and appropriation process; this is not likely to occur. An alternative is to have a multi-year authorization, a single-year appropriation to establish a fund analogous to a university endowment, and an increase in availability of "carry-over" funding. Implicit in this is that the Department of Energy must make a firm commitment to the laboratory.

For the past two years, the national laboratories have been under intense scrutiny. Several groups have reviewed the roles, missions, and performance of these institutions. The Energy Research Advisory Board (ERAB) of the Department of Energy issued its report on the multiprogram national laboratories in September, 1982. The President's Council on Cost Effectiveness (the Grace Committee) has issued a draft report in which considerable discussion was devoted to research in the Department of Energy, and in particular to the national laboratories. Most recently, the White House Science Council issued a report (Packard report) reviewing all government laboratories (not just those operated by the Department of Energy.) Although these reports differ in many ways, they contain several consistent themes:

a. The laboratories are overmanaged by the parent agencies. The term "micro-management" is used to describe this situation. Each of the reports recommends that more autonomy in management be given to the individual laboratories, and in the case of the government-owned-contractor-operated (GOCO) labs, to their contractors.

b. The laboratories need to improve relationships with other research institutions: universities, and especially private industries.

c. The instability and uncertainty of funding for the laboratories prevents them from achieving their optimal usefulness to the nation.

This paper addresses the last item, especially as it relates to the multiprogram laboratories of the Department of Energy. Funding for the research programs at these laboratories is provided on an annual basis. Under current DOE practice, practically all funds must be spent in the year in which they are appropriated. In effect, there is little ability to "carry over" funds from one budget year to the next.*

---

*Funds such as those for multi-year construction items can be carried over.

This in itself would not be particularly onerous if the funding from year to year were relatively stable. Such has not been the case for the past decade. (See Argonne's annual budgets for the years 1975-1983, shown on the accompanying chart.) Budget uncertainties are further complicated by the fact that the total budget at the national laboratories is an aggregation of several smaller budget items, each varying in predictability from year to year.

At Argonne there are 410 different budget control levels. The laboratory has no authority to move funds from one of these categories to another without permission from the Department of Energy, and in some cases, permission from Congressional committees. The combination of the lack of flexibility in transferring money across budget categories, coupled with an inability to plan ahead due to the unpredictability of funding, creates an environment that is detrimental to the performance of first-rate research and development.

As the Packard Committee notes: "The current processes by which laboratories are funded impede rational planning and effective conduct of R&D activities."

It now has been recognized by a number of agencies that more stability is needed if the national laboratories are to operate in an environment appropriate for quality research and development.

The President's Science Advisor, Dr. George Keyworth, and a number of senators have recommended that research and development funds for the national laboratories be authorized and appropriated on a multi-year basis in order to remove the unpredictableness now inherent in the budget process. Senator James McClure, Chairman of the Energy and Natural Resources Committee, and Senator Charles Percy, Chairman of the Foreign Relations Committee and the Committee on Government Operations, have both spoken out publicly for such a multi-year funding policy.

While there are problems in instituting multi-year funding for the national laboratories, it is believed that procedures could be developed that would be compatible with legislative and administrative desires to review the programmatic directions of the laboratories.

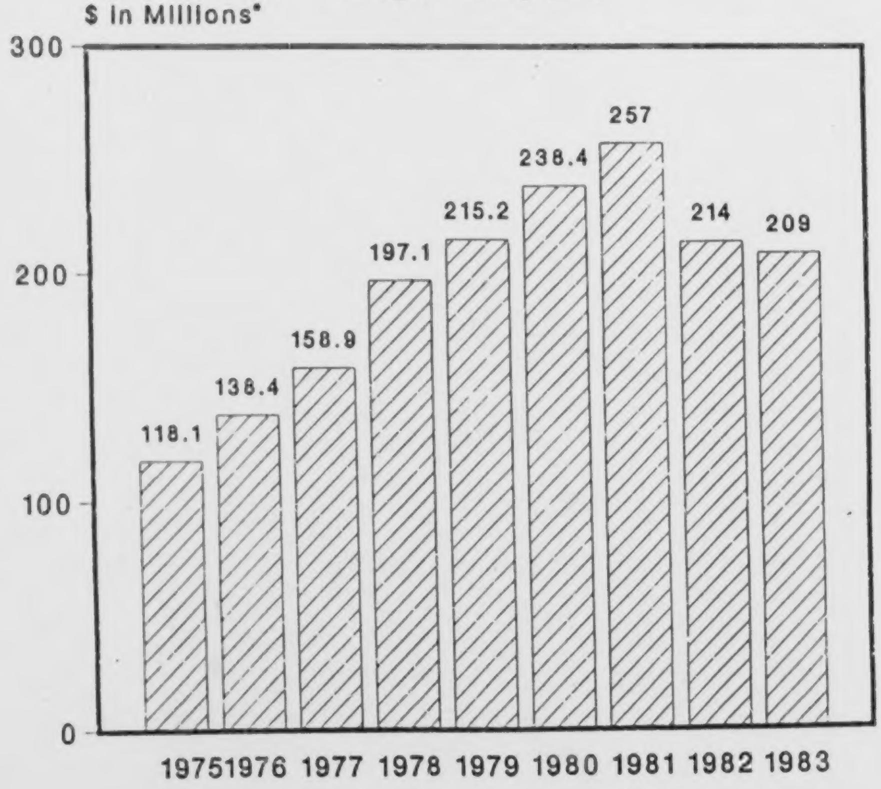
One possible approach is the following:

Congress does not, in a literal sense, act on proposed expenditures, but approves requests for budget authority. The government agencies are granted budget authority (BA) in the form of appropriations, and in turn spend government funds. Although in many cases BA is limited to the current budget year, this is not always true. In some cases, BA is granted for, and extends over several years. One way to initiate a multi-year funding process is to have the appropriate congressional committees, in one given budget year, grant BA for research and development in the various agencies for a two year period. After such a one-time, two year granting of BA, all subsequent budget periods would only have to grant BA for that given budget year. This would, in effect, give research and development a rolling two year appropriation.

Such a process, coupled with a removal of budget ceilings in any given year, i.e., the requirement that all funds authorized in a given budget year have to be spent in that year, would allow the laboratories significantly increased flexibility in planning, and would remove the most onerous aspects of the current process.

This scenario would not require a change in jurisdictions of the oversight committees, nor a decrease in responsibilities of the committees. After a one-time, two year granting of BA, each committee would still approve an annual BA for research and development in each agency. The effect would be that each agency would have, in essence, approximately one year's worth of BA beyond the current budget year. Although this procedure would artificially increase the Federal budget (for one initial year), it would not increase the actual expenditures in any given fiscal year (although there may be some slight increases due to accelerated spending in some agencies; this would more than likely be offset by decelerated expenditures in other agencies.)

OPERATING BUDGET HISTORY
DOE Only
Budget Outlay (BO)



* Current dollars

THE UNIVERSITY OF CALIFORNIA
1868

Lawrence Berkeley Laboratory
1 Cyclotron Road Berkeley, California 94720
(415) 486-4000 • FTS 451-4000

March 20, 1985

Representative Don Fuqua, Chairman
House Committee on Science and Technology
B374 Rayburn HOB
Washington, D.C. 20515

Dear Chairman Fuqua:

Enclosed are answers to the questions which you asked of Dr. Shirley following his testimony on February 28, 1985. If we can provide you with any additional information, please do not hesitate to let me know.

Sincerely.

Martha Krebs

Martha Krebs
Associate Director
for Planning
and Development

Enclosure

Question 1

What programmatic reductions in the FY 1986 DOE budget request cause your FY 1986 operating funds to decrease by $6.2 million? Please present a program by program comparison of LBL's actual and estimated funding for FY 1984, FY 1985, and FY 1986.

Answer

The programmatic reductions in LBL's FY 1986 budget are detailed in Table 1 which compares those reductions to our FY 1984 and FY 1985 budgets.

Table 1

Lawrence Berkeley Laboratory
Statement of Projected Costs
(K$)

DOE Program	FY 1984 Actual	FY 1985 Current Estimate	FY 1986 President's Budget
Nuclear Physics	28,791	29,555	29,500
Basic Energy Sciences	29,310	28,979	28,690
High Energy Physics	17,076	16,883	17,400
Environmental R&D	8,706	8,230	7,005
Magnetic Fusion	7,486	6,543	4,100
Conservation	9,082	9,258	8,240
Solar Energy	3,113	1,580	1,800
Electric Energy Systems and Storage	4,770	4,740	4,050
Geothermal	1,244	1,380	1,200
Fossil	2,527	2,538	1,245
Nuclear Waste Fund	1,003	990	1,160
Other DOE	1,054	990	925
TOTAL DOE OPERATIONS	114,162	111,666	105,315

Question 2

What level of funding is estimated for the Center for Advanced Materials in FY 1986? How does this compare with the level of funding in FY 1984 and FY 1985?

Answer

Table 2 represents the funding levels for the Center for Advanced Materials.

Table 2

Center for Advanced Materials
(M$)

	FY 1984 Actual	FY 1985 Current Estimate	FY 1986 President's Budget
Operating	2.3	2.8	3.2
Capital Equipment	1.2	0.6	not yet allocated

Questions 3 and 4

How many of the "over 700 graduate students earning their advanced degrees while participating in research projects under the direction of LBL scientists and engineers" are actually performing this research at LBL and how many at the Berkeley campus of the University of California?

How many graduate students did LBL support in FY 1984, how many graduate students is LBL supporting in FY 1985, and how many will be supported in FY 1986?

Answer

The latest census of our graduate student population was conducted in calendar year 1983, and indicated that 770 graduate students were involved in LBL research programs. That number has remained essentially constant during 1984 and 1985. We expect the number of graduate students to continue at this level in FY 1986.

About half of students performing research under the direction of LBL scientists and engineers are performing this research primarily in buildings located on the Berkeley campus of the University of California. Space in these buildings is explicitly assigned to LBL use through the UC management contract with DOE. Therefore, this campus space is LBL space. The need for and use of campus space would be reduced, if LBL had sufficient laboratory facilities on its site to serve its programs.

Question 5

You noted that the Bevalac operations will be cut back to about 7-1/2 months if the proposed FY 1986 request prevails. How does this operating schedule compare with the FY 1984 and FY 1985 levels? What is the level of NIH support estimated for each of FY 1985 and FY 1986?

Answer

The Bevalac national research facility provides high energy heavy ions for research in nuclear physics as well as radiobiology and cancer therapy. In FY 1984, the Bevalac provided 3980 hours of delivered beam time in 9 months, a healthy level of utilization for both major programs. In FY 1985, this dropped to 3500 hours in 8 months, and in FY 1986, it will drop again to 3300 hours in 7.5 months. This 17% drop in research hours is compounded by a reduction in force of 30 highly trained technical personnel since FY 1984. Loss of these personnel adversely impacts user support and operating efficiency.

A slowdown now is of particular concern because the facility has recently been upgraded for full-time operation and the research has entered an extremely productive phase. The radiotherapy program is just entering Phase III Clinical Trials, which require a minimum number of patients to receive a full course of treatment. To achieve this number, and thereby assure the support of the physician user community and the sponsoring agency, 9 to 10 months of uninterrupted biomedical running is needed each year. In nuclear physics, the Bevalac is the only facility in the world where scientists can address such forefront issues as the compressibility of nuclear matter and the nuclear equation of state (the relationship between pressure, temperature, and volume in nuclear matter).

The Laboratory has submitted a revised budget request to the Department of Energy for an increase of $2.8 million to restore total Bevalac operations to the FY 1984 levels. The biomedical program alone could be restored to a viable 9-month operation for approximately $1 million.

The National Institutes of Health provides no funding for Bevalac operations. However, NIH does fund 7 grants that support Bevalac biomedical research. In FY 1984 this support totaled $4.8 million. Our current estimate for FY 1985 is $4.6 million. For FY 1986, we are projecting this level of NIH funding to continue.

Question 6

Please provide detailed information concerning LBL's capital expenditure needs of $123 million.

Answer

For some time, the Department of Energy has recognized the fact that the capital facilities of the multiprogram laboratories are in need of replacement, renovation, and maintenance on a cyclical basis. The Multiprogram General Purpose Facility budget item in the Office of Energy Research has been a noteworthy attempt to provide funding for utility and roadway improvements, as well as for buildings which house functions that serve a number of DOE programs. Recently OER has asked its laboratories to update those needs. LBL has undertaken an analysis which would provide for upgrading its plant over a ten-year period. A tabulation of projects and preliminary cost estimates in FY 1985 dollars are listed in Table 3. It should be noted that this list does not include facilities to house new programmatic initiatives such as the CAM buildings. These clearly should be justified independently to the DOE scientific program managers. These are, however, equally important to the long term health of the Laboratory.

Table 3
Lawrence Berkeley Laboratory
Prioritized Get Well Requirements

Title		TEC
Buildings		
1.	Engineering and Technological Support Facility	8.0
2.	50E and 50F Second Floor Additions	3.5
3.	Safety and Supply Services Building	7.0
4.	Building 77 Mechanical Shop Retrofit and Improvements	5.6
5.	Instrumentation Support Laboratory Rehabilitation	1.6
6.	Rehabilitation of Building 6	5.0
7.	Electronics Engineering and Shops Facility	13.5
8.	Building 25 Mechanical Technology Shop Replacement - Phase I	5.0
9.	Multiprogram Research Facility - Increment I	6.2
10.	Instrument Science and Engineering Facility	10.7
11.	Building 69 Conversion to Printing Plant and Photo Lab	2.0
12.	Rehabilitate and Improve Building 90 Office Building	1.7
13.	Multiprogram Research Facility - Increment II	6.1
14.	Building 25 Mechanical Technology Shop Replacement - Phase II	5.0
	Total	80.9
Utilities		
1.	Electrical System Rehabilitation and Improvements	2.6
2.	Rehabilitation of Site Mechanical Utilities - Phase I	5.5
3.	Original Labsite Substation	2.4
4.	East Canyon Substation and Feeders	2.9
5.	Sitewide Electrical Equipment	2.8
6.	Rehabilitation of Site Mechanical Utilities - Phase II	3.6
	Total	19.8
Other		
1.	East Canyon Corporation Yard - Phase I	4.6
2.	Environmental Health and Safety Projects	6.7
3.	Slope Stabilization above the Bevatron, Building 51, and Mechanical Shops, Building 77	2.9
4.	Shipping, Receiving, and Transportation Facilities	3.1
5.	Roadway Safety and Parking Improvements	3.8
	Total	21.1
TOTAL		121.8

Question 7

You recommended that once programs are begun, stable funding be maintained through their completion. Given the uncertainties of the budget process, how might this best be done?

Answer

I want to answer this question specifically for the OER basic research programs, which have not fared well in the FY 1986 budget compared to programs of equivalent scientific quality in the DOD, NSF, and NASA. In addition, the programs play a critical role in meeting DOE's long range technology goals as well as broader national needs for technological innovation and competitiveness. They are also the primary DOE programs training the next generation of energy scientists and engineers both in universities and national laboratories. I think the Committee knows this and by its actions in the past has supported these programs strongly.

The need for stable funding for basic research programs especially those with a strong educational mission has been recognized by both the Executive Branch and Congress. Strong and continuing commitment and attention through the whole budget process is required to maintain this stability. Recently, there has been a trend not only to stability, but growth; it is welcome. The continued growth of basic research overall in the FY 1986 budget is also welcome; however, omission of the DOE basic research programs in FY 1986 is a dangerous, destabilizing oversight that should be corrected. To make such a correction for FY 1986 requires Congress' commitment.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37831

March 29, 1985

RECEIVED
APR - 2 1985
COMMITTEE ON SCIENCE
AND TECHNOLOGY

The Honorable Don Fuqua, Chairman
Committee on Science and Technology
Suite 2321
Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Fuqua:

Enclosed is the Oak Ridge National Laboratory's response to your March 5, 1985, inquiry. I appreciated the opportunity to testify before the Subcommittee on Energy Development and Applications on February 28, 1985, and hope that this supplemental information will be helpful to the Committee.

Please note that the budget estimates shown for FY 1986 are based on our understanding of the President's submission and do not include the effect of any Congressional redirection of DOE funds.

ORNL wishes to cooperate in any way possible with the Committee's Science Policy Task Force. Due to the prominent position of the national laboratories in U.S. science, I urge the Committee to seek input from national laboratories in its study. In particular, I would offer my services and those of my staff to serve on panels for the Task Force and to assist in other ways deemed appropriate.

Please contact me if I can be of further assistance.

Sincerely,

Herman Postma

Herman Postma
Director

HP:jas

Enclosure

File-RC

Oak Ridge National Laboratory
Responses to Hearing Questions
Subcommittee on Energy Development and Applications
March 21, 1985

1. What steps is Oak Ridge National Laboratory (ORNL) taking to participate in truly cooperative and collaborative research projects with its regional universities?

   ORNL maintains close ties with many universities throughout the world. However, the Laboratory has always recognized its unique position as a major research center in the Southeast and participates in a wide variety of cooperative and collaborative projects with regional universities. Of more than 900 university faculty and students who participated in ORNL programs in 1984, approximately one-third were from 30 universities in the Southeast. This included more than 150 guest faculty and students from regional universities who performed cooperative research at ORNL, more than 60 area graduate students who utilized the Laboratory as a resident research campus, and students and faculty from 22 regional universities who participated in research programs at unique ORNL user facilities. In addition, more than $12M in research subcontracts with regional universities was in force in 1984. Particularly noteworthy in these interactions has been ORNL's close ties with The University of Tennessee at Knoxville, with the 50-member Oak Ridge Associated Universities organization, and with the region's historically black colleges and universities.

   A recent initiative, the ORNL-University of Tennessee Science Alliance, has ushered in a new era in laboratory-university cooperation. In this program, combined funds from ORNL and the State of Tennessee are being used to create centers of excellence in a variety of fields including nuclear physics, bioprocess research, tomography, and measurement and control engineering. Eventually 30 such centers are envisioned with a combined budget of $30M to operate and equip laboratories and attract outstanding faculty/scientists. Another unique example is the Joint Institute for Heavy Ion Research which is supported through a combination of University of Tennessee, Vanderbilt University, and ORNL funds to facilitate regional cooperation in research at ORNL's Holifield Heavy Ion Research Laboratory.

   The Laboratory provides many kinds of service to regional universities; among them, for example, is an arrangement whereby Florida State University scientists can access the DOE computer at Livermore by using the ORNL satellite link.

2. What steps is ORNL taking to participate in truly cooperative and collaborative research projects with its regional industrial communities?

ORNL cooperates in research projects with industries throughout the United States. In 1984, there were approximately 300 industrial scientists who participated in ORNL research programs as guests, through cost-sharing arrangements, and as users of ORNL research facilities. The Laboratory is committed to the transfer of technology and the establishment of new industry with particular emphasis on the East Tennessee region. The newly established Tennessee Innovation Center is privately funded by our contractor organization (Martin Marietta Energy Systems, Inc.) at $1M/yr to encourage regional development of new products and industry using ORNL technology. Currently, five examples of ORNL technology in areas such as robotics and instrumentation are being developed with local industries. ORNL participates with several area industries through the ORNL-University of Tennessee Measurement and Controls Engineering Center and the recently dedicated American Welding Institute in Knoxville. In addition, Martin Marietta Energy Systems, Inc., is committed to placing $15M annually in R&D and technology-related subcontracts with area industries and is developing a multimillion dollar industrial park in Oak Ridge for new technology ventures.

3. How does ORNL's overall budget projected for FY 1986 compare with the current year's budget? Please present a program by program comparison of ORNL's actual and estimated funding for FY 1984, FY 1985, and FY 1986.

ORNL budget data by program are shown in the following table for FY 1984 (actual cost), FY 1985 (current plan), and FY 1986 (estimated using the President's Budget where available). The data indicate that the FY 1986 ORNL operating budget for DOE programs will decrease approximately 5% when compared with FY 1985, corresponding to a loss of 10% when adjusted for inflation. Based on this comparison, ORNL projects a reduction in employment in 1986 of up to 400 personnel, including 200 scientific and technical staff members.

Oak Ridge National Laboratory
Budget Analysis (BO in thousands)

Program	FY 1984 Actual	FY 1985 Current	FY-1986 Estimate	FY 1985-86 Change
AA Coal	9213	9441	6465	-31%
AB Gas	59	100	0	-100%
AE Advanced Nuclear Systems	2132	1704	1770	+4%
AF Breeder Reactor Systems	10636	14964	6409	-57%
AG Converter Reactor Systems	5024	4324	4065	-6%
AH Remedial Action Programs	3217	6312	10230	+62%
AK Electric Energy Systems	6533	6343	4515	-29%
AL Energy Storage Systems	2056	1460	595	-59%
AM Geothermal	50	60	40	-33%
AP Commercial Nuclear Waste Mgnt.	378	232	15	-93%
AR Defense Waste & By-Products Mgmt.	20950	22378	21628	-3%
AS Nuclear Fuel Cycle	23329	11427	16800	+47%
AT Magnetic Fusion	58386	56431	52326	-7%
CC Geothermal	82	90	50	-44%
CD Uranium Enrichment	270	859	350	-59%
CE Hydropower	217	172	0	-100%
CH Alternate Fuels Production	45	187	0	-100%
DB Nuclear Waste Fund	0	3279	1333	-59%
DC Civilian Radioactive Waste	1653	40	0	-100%
EB Solar Energy	3932	5765	5244	-9%
EC Buildings & Community Systems	9907	14744	10493	-29%
ED Industrial	1131	1527	1382	-9%
EE Transportation	3204	7498	8990	+20%
EF State/Local Programs	538	167	0	-100%
EG Multi-Sector	2829	4825	5062	+5%
GC Verification & Control Technology	161	297	330	+11%
GD Nuclear Safeguards & Security	0	350	400	+14%
GE Materials Production	6993	8102	8597	+6%
HA Environmental Res. & Development	28640	31699	28177	-11%
HB Life Sciences Res. & Nucl. Medicine Appl.	2229	0	0	0
KA High Energy Physics	589	450	450	0
KB Nuclear Physics	9644	10118	10030	-1%
KC Basic Energy Sciences	48010	51397	53200	+4%
KD Energy Research Analysis	644	1317	600	-54%
KE University Research Support	187	300	320	+7%

Oak Ridge National Laboratory
Budget Analysis (BO in thousands)

(continued)

Program	FY 1984 Actual	FY 1985 Current	FY-1986 Estimate	FY 1985-86 Change
LA Technical Information Mgmt.	986	1131	1147	+1%
LD Consumer Affairs	0	13	0	-100%
PE Policy Analysis & System Studies	28	32	0	-100%
TA Collection, Production & Analysis	2655	1600	600	-62%
TB Program Services	148	225	100	-56%
UB Utility Prog. and Regulatory Interview	85	209	54	-74%
UC Compliance	62	13	39	+200%
VI Fed. Energy Reg. Comm.	5	0	0	0
VF Other Expenses	472	779	260	-67%
XB In-House Energy Mgmt.	70	272	0	-100%
XX ORNL Environmental Upgrade	0	5510	12780	+132%
TOTAL DOE PROGRAMS	267379	288143	274846	-5%

4. What has been ORNL's role to date in the development of the so-called "Steel Initiative" originating with the Office of Science and Technology Policy?

The Oak Ridge National Laboratory has been involved in the Steel Initiative since March 1984. We attended several meetings organized by the American Iron and Steel Institute to learn about the needs of the U.S. steel industry to develop new technology and thereby increase their competitiveness in the face of ever-increasing imports. Participants at these meetings included representatives of the steel industry, Oak Ridge National Laboratory, Argonne National Laboratory, and the National Bureau of Standards. It was determined that there is a strong likelihood that these three Federal research laboratories could indeed help the steel industry to develop new technologies. Four principal areas were identified for research: (1) new methods of iron ore reduction; (2) new technology of near-net-shape casting; (3) thermal-mechanical treatment of sheet steel to improve quality and reduce the number of grades; (4) applications of modern sensors, automation and control technology, and artificial intelligence to the steel industry. The Oak Ridge National Laboratory took the lead role in items (3) and (4). To that end we convened workshops held at Oak Ridge which included steel industry representatives, university scientists, and scientists and engineers from national laboratories including Oak Ridge. These workshops produced research plans which were then reviewed by the Steel Initiative Steering Committee, and amended and approved by that Committee. Two members of the Laboratory serve on the Steering Committee, Dr. Alexander Zucker and Dr. J. O. Stiegler. At the present time ORNL has developed a conceptual design for an experimental thermal-mechanical research laboratory and has submitted fund requests to build and operate it. We have also developed a research plan for the sensor-automation research program and submitted a fund request for it. We are further proceeding with plans to do research on filtering of steel with ceramic filters where the Laboratory has strong expertise.

It is our view that the national laboratories represent an important national asset which can be used by the U.S. to further its competitive position. We view the steel initiative as a first step and we expect that because of the enthusiasm of the steel industry in this endeavor and because of the relevant expertise in Oak Ridge a fruitful and productive relationship can result.

5. Would you like to comment on the Committee's Science Policy Task Force Report, An Agenda for a Study of U.S. Science Policy? What important issues concerning the government laboratories in general and your laboratory in particular do you believe should be included in the Task Force's study?

The report, An Agenda for a Study of U.S. Science Policy, raises important and timely questions and presents an excellent basis for reviewing national science policy. The proposed agenda is complete and addresses those issues which are crucial in determining the future of science in the U.S. We have no issues to add to that very comprehensive list, except to note that it is an ambitious undertaking.

Since national laboratories play such an important role in the overall U.S. scientific enterprise, the Committee has properly devoted section II-B of the agenda to this issue. In partial response to question 3 in this section, I would note that the DOE multiprogram laboratories (including ORNL) have been extensively reviewed over the past few years including the Grace Commission Report, the OSTP Report of the Federal Laboratory Review Panel, the ERAB Report on DOE Multiprogram Laboratories, and the DOE Assessment of the Basic Energy Sciences (BES) Program. All of these studies have indicated that the multiprogram laboratories are a unique national resource performing high quality research and development. In the area of basic research, it was demonstrated that BES programs at national laboratories were comparable or slightly higher in quality than BES university programs. These studies also emphasize the need for a well-defined mission for DOE and the national laboratories. This mission uncertainty for DOE's energy R&D laboratories is likely to be resolved in the next few years as the world economic recovery reduces energy supplies.

ORNL is committed to a strong future for science in the U.S. and will support the Committee's study in any way possible. In particular, I would urge that input from national laboratories be sought by the Committee and that national laboratories be represented on panels established by the Committee. I am pleased to offer my services and those of the appropriate members of our senior staff for this purpose.

PANEL 3: HIGH ENERGY AND NUCLEAR PHYSICS

Mr. FUQUA. And now we will begin with Dr. Schiffer, Chairman of the DOE/NSF Nuclear Science Advisory Committee, also from Argonne National Laboratory.

STATEMENT OF DR. JOHN P. SCHIFFER, CHAIRMAN, DOE/NSF NUCLEAR SCIENCE ADVISORY COMMITTEE, ARGONNE NATIONAL LABORATORY, ARGONNE, IL

Dr. SCHIFFER. Mr. Chairman, I appreciate this opportunity——

Mr. FUQUA. We will make your prepared statement a part of the record; if you wish to briefly summarize, that would be fine.

Dr. SCHIFFER. I would also ask for permission to show a few transparencies.

Mr. FUQUA. Certainly. Certainly.

Dr. SCHIFFER. Last year I reported to you on—I speak as Chairman of DOE/NSF's Science Advisory Committee. Last year I reported to you on our long-range plan in which we tried to summarize the aspirations and hopes and plans for our science, with some consideration on the budgetary implications, over roughly the next 5-year period. We saw major opportunities, scientific opportunities for construction of new facilities, and we recommended the 4-GeV electron accelerator; and subsequent to that, we saw an exciting opportunity in the relativistic heavy-ion collider.

I have been asked to summarize the status of NSAC proceedings in the last few months. In particular, there were two activities that our committee was asked to undertake. One was a request from Dr. George Keyworth through the DOE/NSF to review the scientific justification of a 4-GeV electron accelerator. The subcommittee which reported on that—the report of that subcommittee should be a part of the record.

We were also asked to undertake a review of the long-range plan, update it, and that we undertook and submitted a report this last November.

Substantively, these two activities reaffirmed the scientific priorities that we saw in the long-range plan. We see nuclear science over the next 5-year period as consisting of a number of components. There is an ongoing base of 9 national facilities, 12 smaller dedicated university facilities, which provides the ongoing activity of research in nuclear physics and which is the mainstay of both the thinking, the scientific development, and the training for graduate students that our science engages in.

We made a major point of the need for utilization at these facilities and because of increasing complexity of the challenges, the scientific challenges facing us for the need of increased instrumentation, and we asked for some 10 percent increment to that base program.

A particularly exciting frontier for our field is to understand the point of how the realm of quark/gluon physics interfaces into nuclear physics.

To understand how the substructure of nucleons shows up, we proposed the two major facilities I referred to.

Last year's activity reaffirmed the scientific justification of a 4-GeV electron accelerator as the highest priority major construction item for our field. Our subcommittee recommended further following on the long-range plan, that a structured program of research should be pursued in electromagnetic research, with a 4-GeV accelerator being the flagship and some smaller facilities be upgraded in the capability for lower energy research to complement the work that is going on.

The heavy-ion collider brings us into a new, possibly entirely new, realm of physics where the distinctions between protons and neutrons disappear and where there is a possibility of a phase transition of muclednic or hadronic matter into something which has been termed a quark/gluon plasma. We are most excited in pursuing that scientific opportunity, but it's after the 4-GeV electron accelerator in priority.

We emphasize the importance of graduate training, of training new students and new scientists. This has been echoed a number of times this morning and all I can do is reiterate the statement that it is important not only for the health of the science, but also for the national welfare, that people trained in sciences such as nuclear science continue to make a major impact on the whole fabric of our society and must be an integral, continuing resource to a high technology economy such as ours.

The budgets continue to be tight. We did an historical perspective of the budget in the long-range plan, and the first transparency—this is the support in investment in basic research in nuclear science over the past 15 years. There was a decline in the late 1960's, early 1970's, then a slower decline throughout the 1970's; and at the time of the long-range plan there was some source of optimism. The red line indicates the present fiscal year 1985 and the projected fiscal year 1986 budgets.

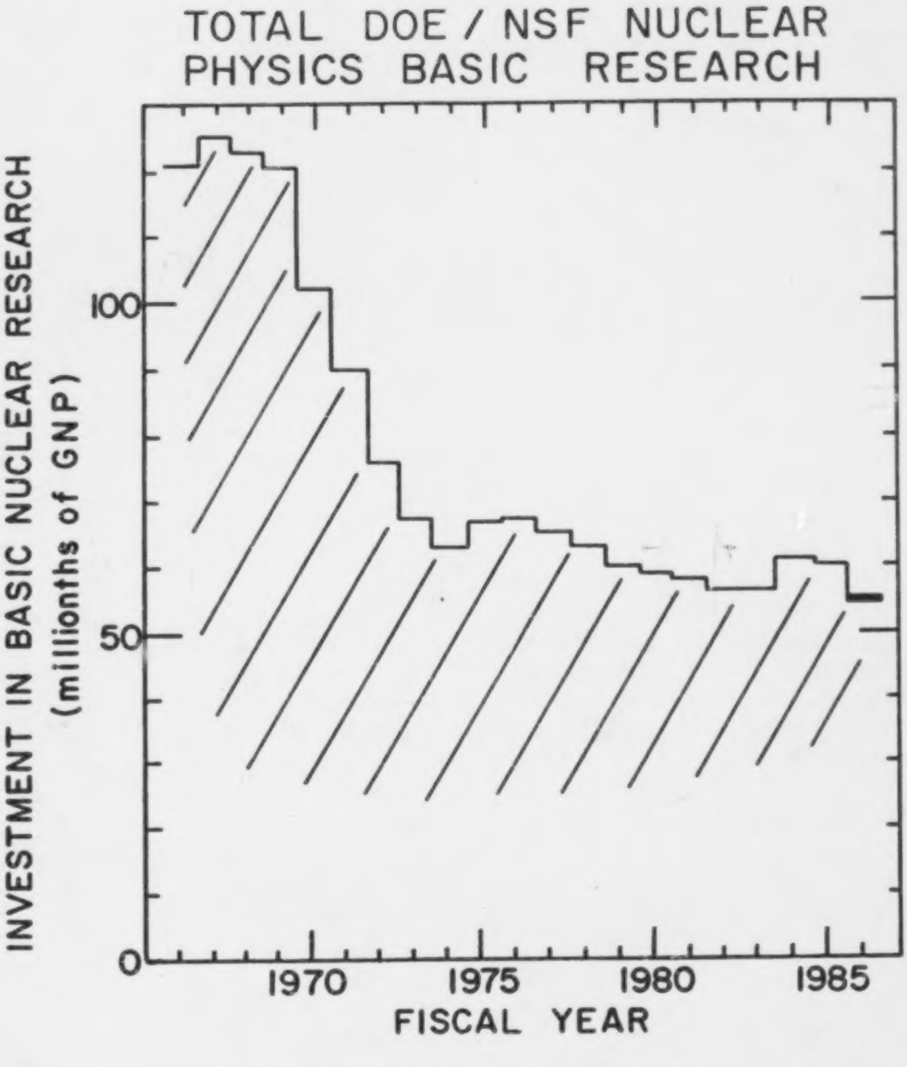


Figure 1 Total federal budgets for basic nuclear research.

We regret that this implies further reduction in utilization of our facilities, delays, and compromises in instrumentation. We regret that the construction of CEBAF is being delayed, and we also regret that a facility which is of considerable interest to our science, which was recommended by the High Energy Physics Advisory Panel, the booster to the AGS accelerator, has been delayed.

Budgets are tight, but our science must go on. I am in complete accord with the statements that were expressed this morning about various support in various areas of research, but I would like to show a few examples of ongoing activity. Things are happening and we are doing the best we can with limited resources.

One construction project has been completed in this last year, and that is the ATLAS facility at Argonne which uses an entirely new technology, superconductivity, for acceleration of particles. Superconductivity has been used now for a number of years for magnets, to contain particles in their orbits, in high energy physics in particular. This facility uses superconductivity to accelerate particles in a highly efficient, precision way. This accelerator is being completed on schedule and on budget, and the first beams are expected this spring. It is also a technology that has applications and is being copied at a number of universities, including Kansas State University, Florida State University, and a number of universities abroad.

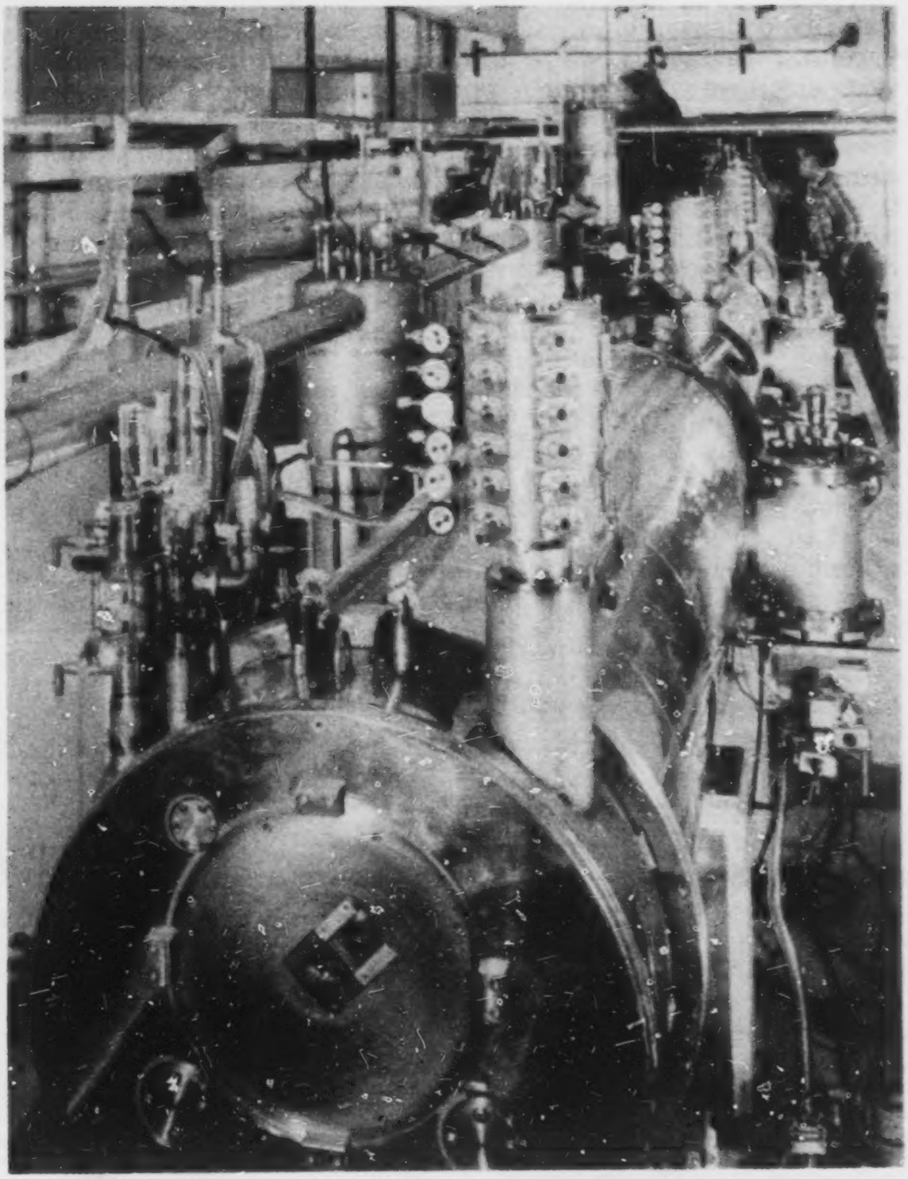


Figure 2 Assembly of ATLAS, a unique heavy-ion accelerator based on new superconducting technology developed, at Argonne National Laboratory.

Another small project that has been completed is an electron injector at the High Energy Physics Laboratory at SLAC for nuclear physics research. This is a very modest attempt to touch on a small fraction of the physics which we hope to address with the full 4-GeV electronic accelerator when that becomes completed. This has been completed and is ready for research.

The university upgrades are underway, particularly two of them in the DOE program at the University of Washington at Seattle, and at Yale, universities which are mainstays of our program in graduate training.

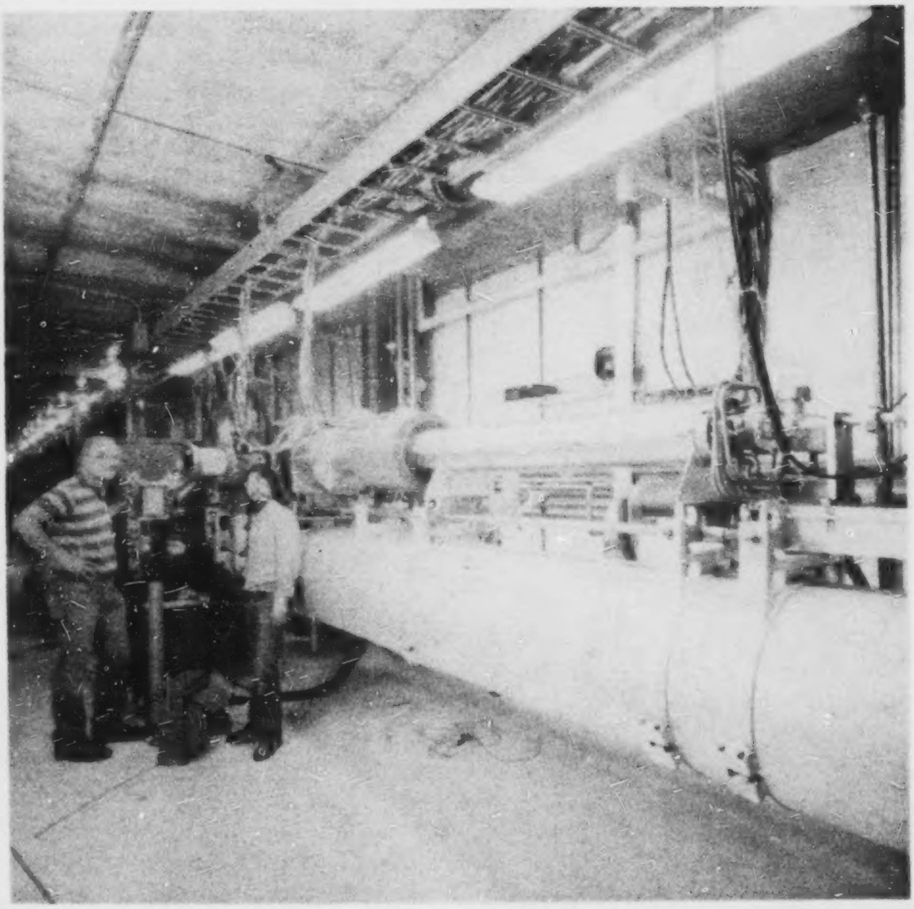
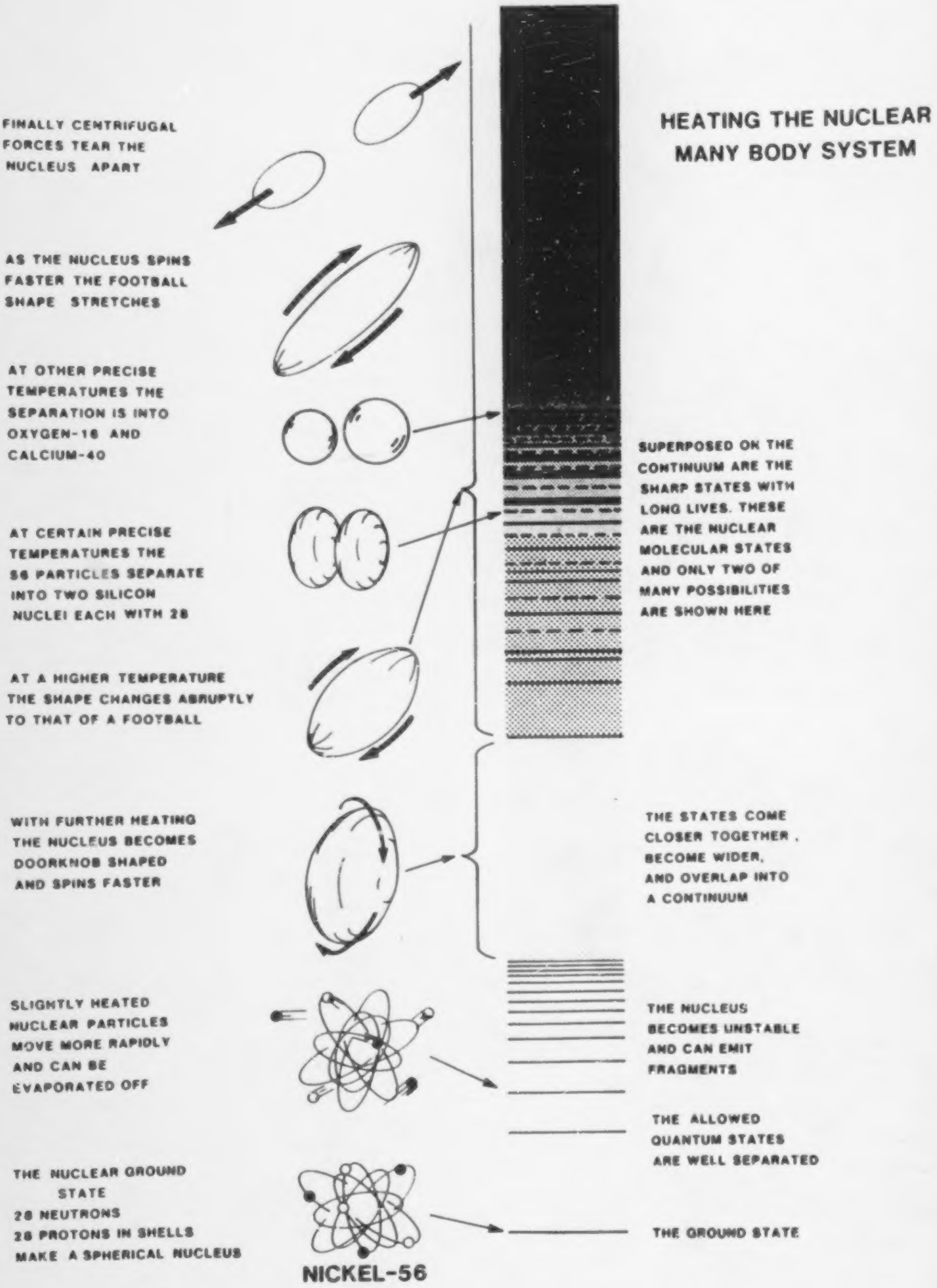


Figure 7 The new 'nuclear physics' electron injector at the Stanford Linear Accelerator Laboratory at endstation A.

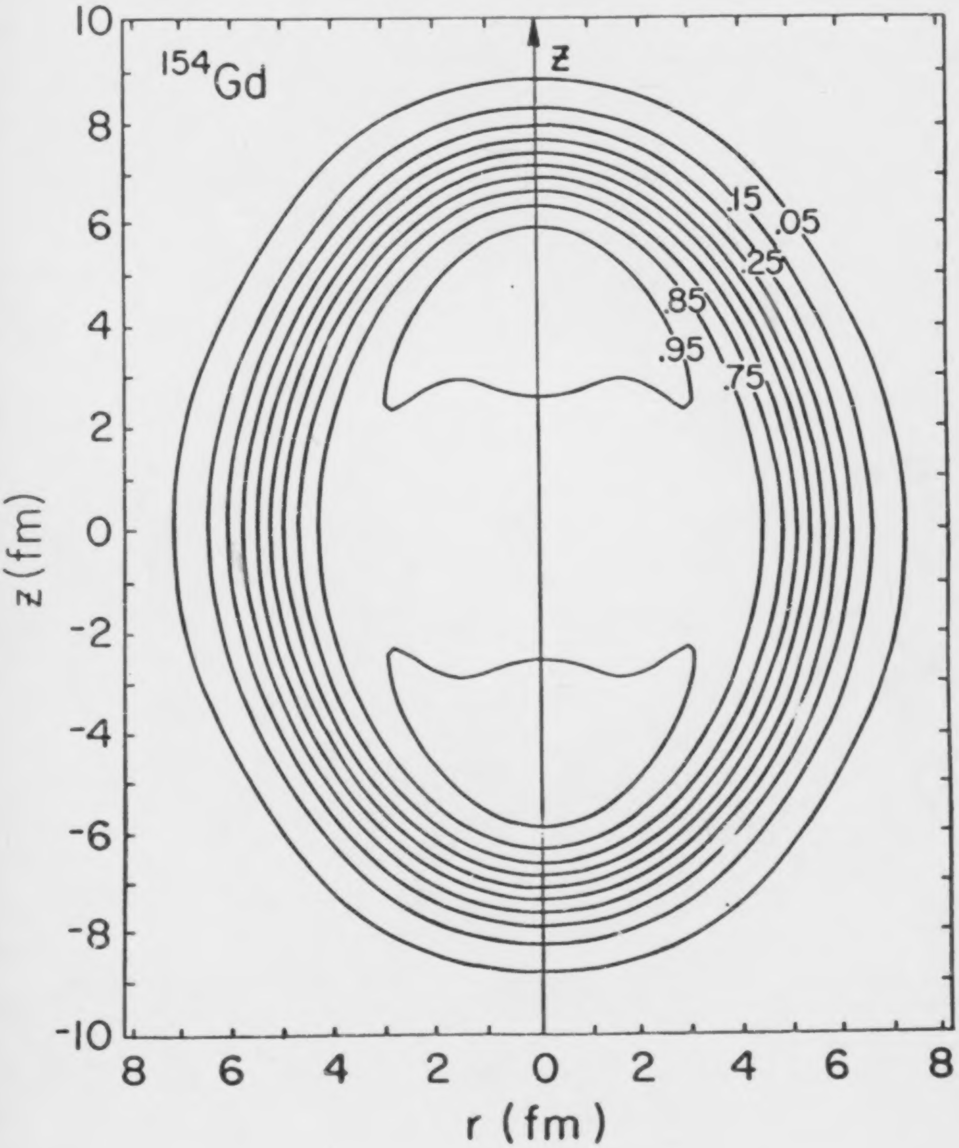
The importance of electromagnetic research is great for our field. I'd like to show an example, in the next transparency, of how nuclear shapes change as the rate of rotation of a nucleus changes. This is modeled on the nucleus that has been extensively studied at Yale University, Brookhaven, and Argonne, and it shows as the nucleus rotates with increasing rapidity its shape changes; it undergoes—it splits into two components, both symmetric and asymmetric. This comes from heavy-ion research.

Figure 3 Schematic of the evolution of a nucleus, that has been extensively studied at the Yale Nuclear Structure Laboratory, as a function of increasingly rapid rotation.


HEATING THE NUCLEAR MANY BODY SYSTEM
FINALLY CENTRIFUGAL FORCES TEAR THE NUCLEUS APART
AS THE NUCLEUS SPINS FASTER THE FOOTBALL SHAPE STRETCHES
AT OTHER PRECISE TEMPERATURES THE SEPARATION IS INTO OXYGEN-16 AND CALCIUM-40
SUPERPOSED ON THE CONTINUUM ARE THE SHARP STATES WITH LONG LIVES. THESE ARE THE NUCLEAR MOLECULAR STATES AND ONLY TWO OF MANY POSSIBILITIES ARE SHOWN HERE
AT CERTAIN PRECISE TEMPERATURES THE 56 PARTICLES SEPARATE INTO TWO SILICON NUCLEI EACH WITH 28
AT A HIGHER TEMPERATURE THE SHAPE CHANGES ABRUPTLY TO THAT OF A FOOTBALL
WITH FURTHER HEATING THE NUCLEUS BECOMES DOORKNOB SHAPED AND SPINS FASTER
THE STATES COME CLOSER TOGETHER, BECOME WIDER, AND OVERLAP INTO A CONTINUUM
SLIGHTLY HEATED NUCLEAR PARTICLES MOVE MORE RAPIDLY AND CAN BE EVAPORATED OFF
THE NUCLEUS BECOMES UNSTABLE AND CAN EMIT FRAGMENTS
THE ALLOWED QUANTUM STATES ARE WELL SEPARATED
THE NUCLEAR GROUND STATE 28 NEUTRONS 28 PROTONS IN SHELLS MAKE A SPHERICAL NUCLEUS
THE GROUND STATE
NICKEL-56

With electron scattering—on the next transparency—at the present facility at MIT Bates Laboratory, one can map out in some detail the shape of a nucleus in its lowest state. And we can see what remarkable precision electron scattering is capable of. The present Bates facility is very limited and with continuous beams such studies could be carried out much more extensively and systematically. This is a prototype of the results one could obtain.

Figure 6 The charge density of a spheroidally deformed nucleus deduced from precision electron scattering experiments at the MIT Bates Laboratory.



New techniques are being brought in. The next picture shows an intriguing array of gamma ray detectors which was developed at the Berkeley Laboratory at the 88-inch cyclotron. It's a multiarray gamma ray detector which, by study of coincidences between a large number of gamma rays, can deduce the changes in shape and other properties of nuclear systems under rapid rotation that I showed previously.

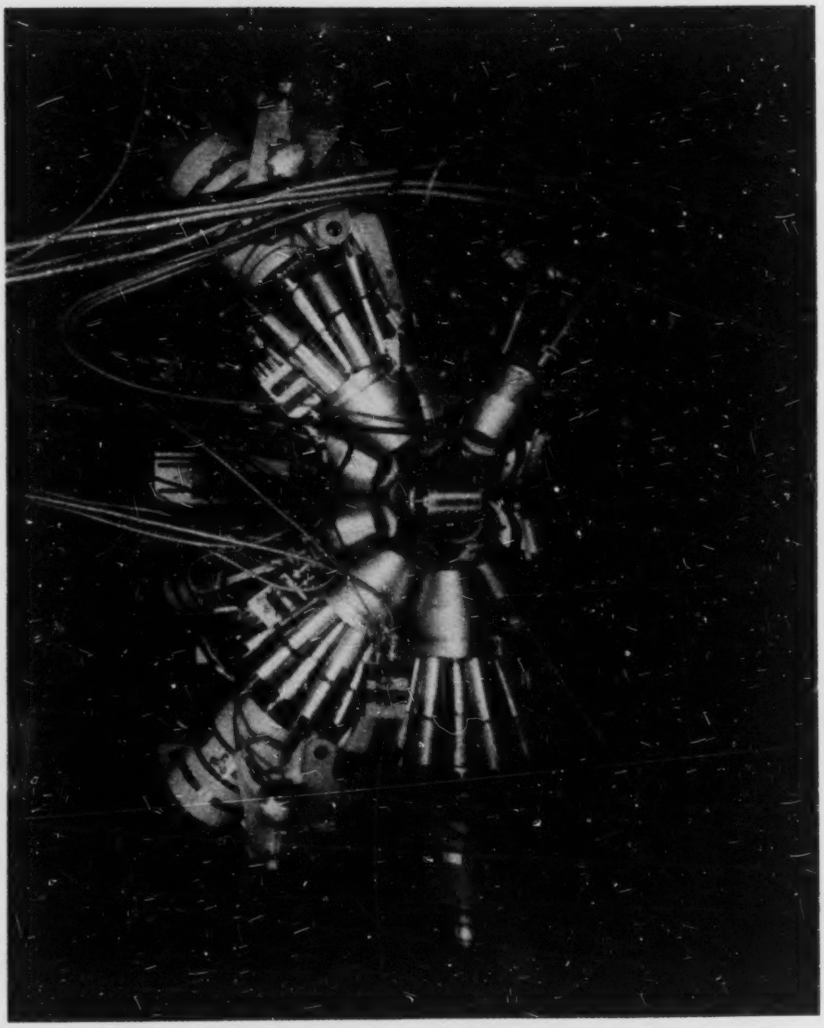


Figure 4 The new Compton-suppressed gamma-detector array 'HERA' at the Lawrence Berkeley Laboratory.

As one goes to higher energies, new phenomena are beginning to emerge from nuclear collisions. On this transparency I couldn't resist showing—it's a very recent result, and it's a composite of an international endeavor at four laboratories: at CERN, at the French Heavy-Ion Laboratory, at Michigan State University, and at Oak Ridge National Laboratory. It is remarkable because it shows that pions, the particles that represent the nuclear glue, are produced in a way where all the energy in collision between 2 heavy nuclei, 2 carbon nuclei—24 neutrons and protons collide and give up 80 percent of their energy to 1 particle of nuclear glue. That was entirely unexpected, and this result is unexplained. But it shows that in this domain, qualitatively new phenomena are happening which we are attempting to understand.

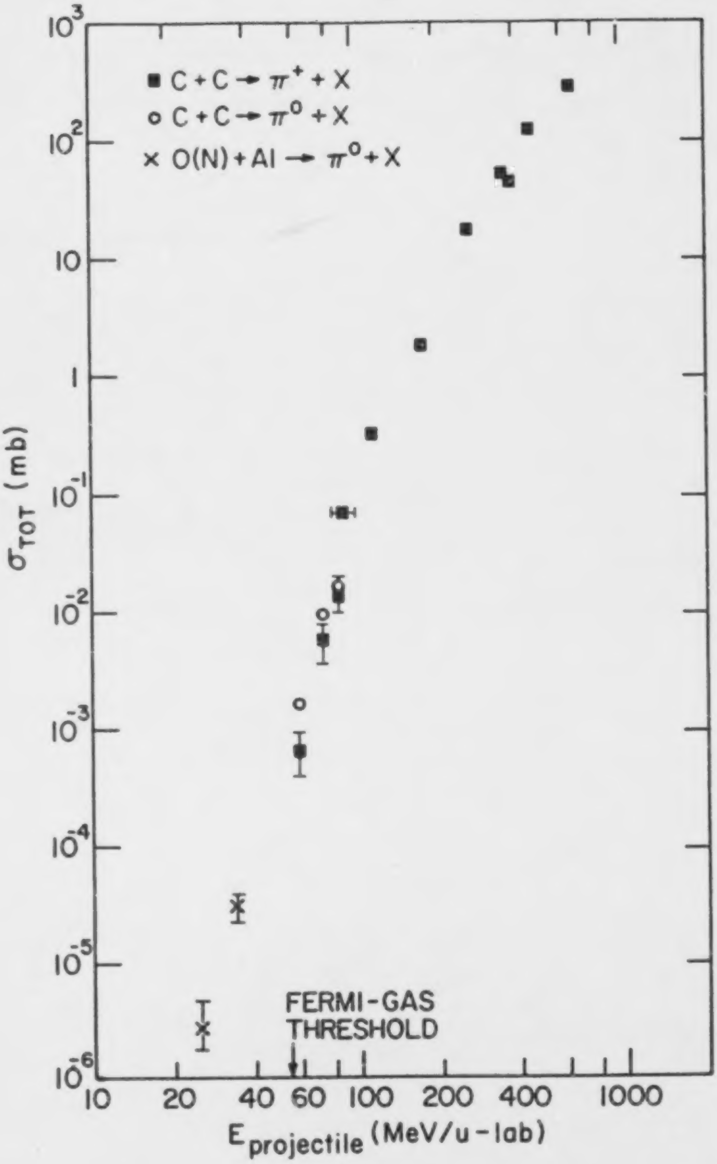


Figure 5 Pion production from the collision between low-velocity heavy ions. The data shown were obtained at a number of laboratories in the U.S. and Europe including Oak Ridge National Laboratory.

In going to higher energies, the mainstay of a research program, heavy-ion research, is the Bevalac. There, again, in international collaboration with a German group, we built a large detector system called plastic ball which is shown here, and from this important results have emerged in the last year, shown in the next transparency, which indicate the path we would like to follow.

The properties of nuclear matter under the compression that can be achieved at the Bevalac behave in a way that was predicted by theory, the same theory which predicts that at even higher energies one will reach the quark/gluon plasma, the phase transition that I referred to earlier. So with available facilities we are probing nuclear properties of nuclear matter, and so far the predictions are consistent.

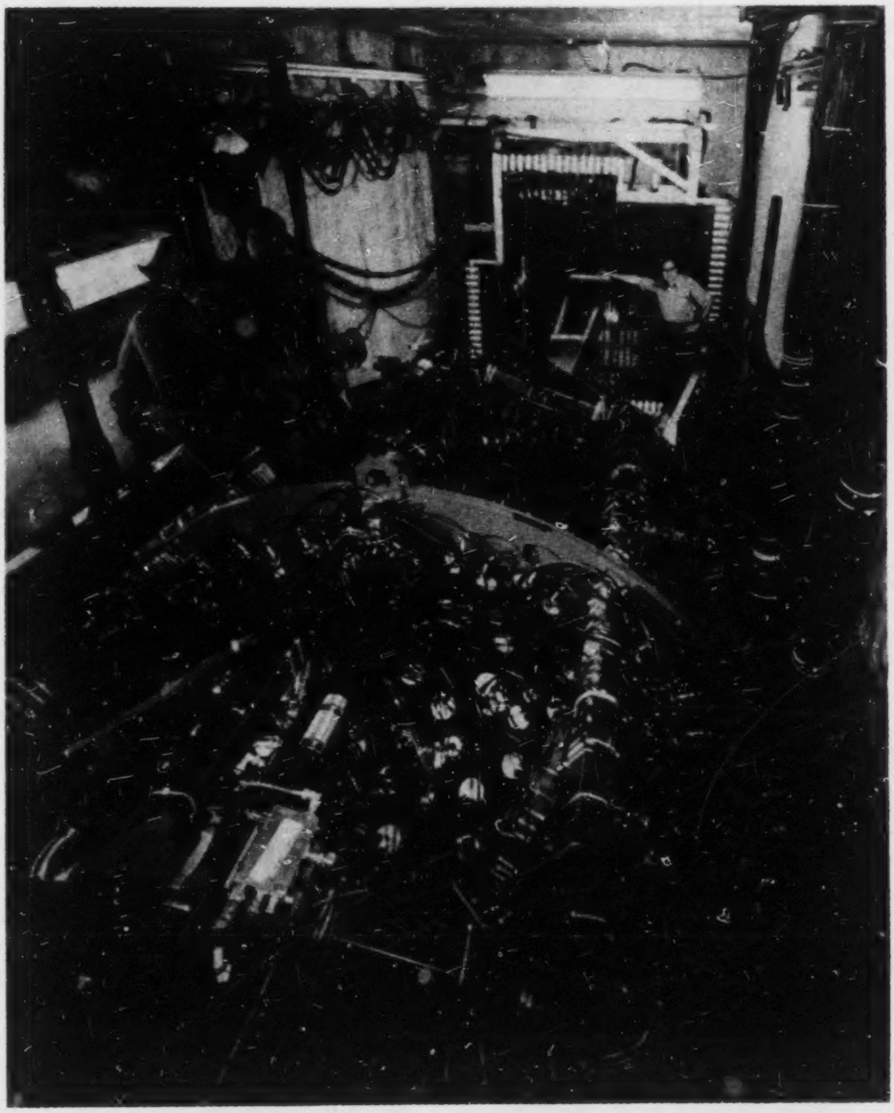


Figure 8 The Berkeley 'plastic ball' used in key experiments to study the collision between relativistic heavy ions.

The latest step on this path has been undertaken in a very modest way by injecting heavy ions into the Brookhaven AGS. The facility there will produce oxygen and sulfur beams at higher energies than at Berkeley and probe this equation of state further but not at energies sufficient to reach the quark/gluon plasma. This we hope will be available for research in about 1½ or 2 years.

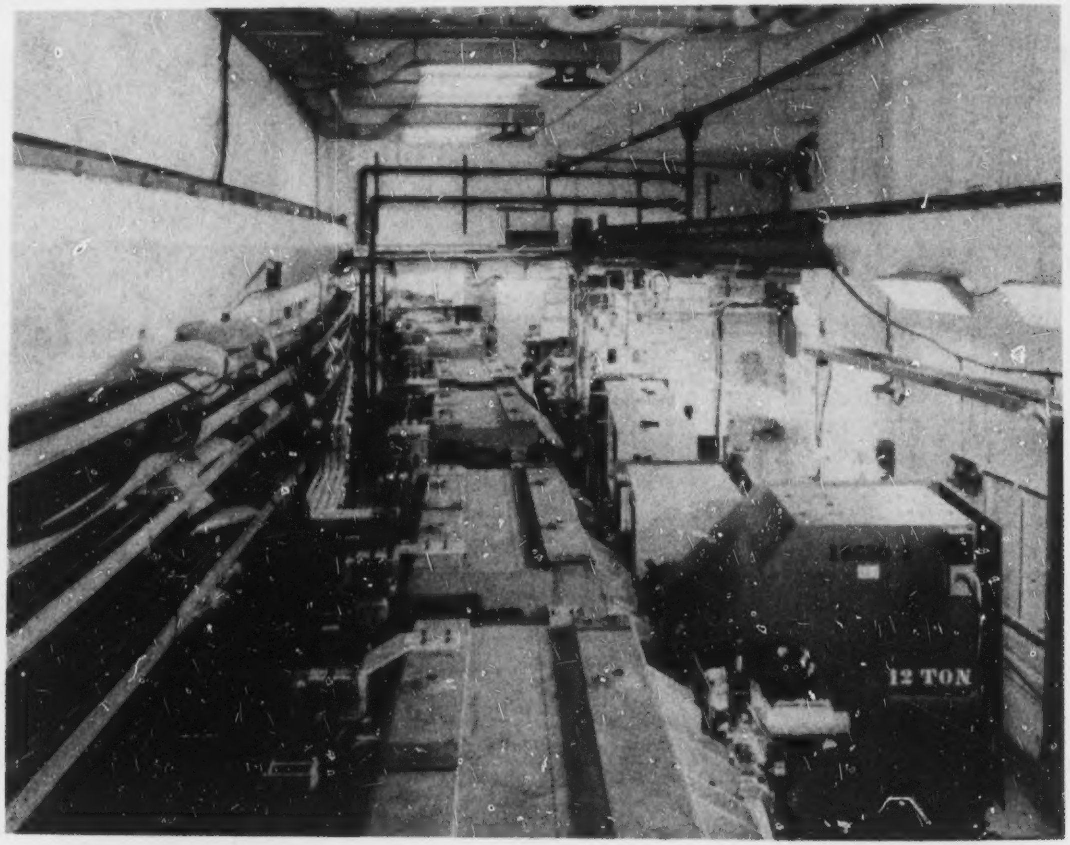


Figure 9 A view of the AGS tunnel at Brookhaven National Laboratory showing a part of the accelerator with the beam line where the 15 GeV/u oxygen beam will be extracted when the heavy-ion injector is completed.

The scientific opportunities that we have in front of us in nuclear science are real. We would like to get on with the new initiatives that are beginning to press on us very hard. We have lost in the last few years considerably to international competition. Laboratories in Germany, in France, in Switzerland are increasingly at the leading edge of our field. If we can get on with the new facility constructions that we foresee, the level of support that we suggested in the long-range plan, the United States can regain its position of leadership or at least equal partnership in the ongoing effort of research.

We feel that it is important that we do this on many levels. It's important intellectually. There are very important questions of physics to be answered. It is also important for us to continue to attract young people and train young people in a science where these young people then have a major impact on society's goals in achieving the high-technology society for which this country is striving.

Thank you very much.

[The prepared statement of Dr. Schiffer follows:]

HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS

Statement of John P. Schiffer

Argonne National Laboratory and University of Chicago

Chairman, DOE/NSF Nuclear Science Advisory Committee

February 28, 1985

Mr. Chairman and members of the Subcommittee

Thank you for this opportunity to testify on the status of the plans and aspirations of nuclear physics, in connection with the DOE budget hearings. Last year in my testimony to this Subcommittee I summarized the Long Range Plan for Nuclear Science which our scientific community, as represented by the DOE/NSF Nuclear Science Advisory Committee (NSAC) had formulated in late 1983.

In that Plan we recognized the exciting recent developments in nuclear physics which are closely related to developments in the other subfields of physics. This is especially true of the two areas where we saw opportunities for major new facilities, the 4-GeV electron accelerator and the relativistic heavy-ion collider. These facilities will probe the properties of the nucleus and of nuclear matter beyond neutrons and protons, merging into the regime where the role of quarks and gluons in the nuclear many-particle systems becomes evident.

I would like to summarize the developments of the past year in our science and the two recent studies that NSAC was asked to undertake in connection with the Long Range Plan.

Since these hearings concern budgets I would first of all like to comment on this subject very briefly. In the Long Range Plan we reviewed federal support for Nuclear Science and commented on the decline in this support over the past decade, as is shown in Figure 1. We also noted the relative strength (by a factor of three or four) of such support in other technically advanced countries. We projected a budgetary plan corresponding to our scientific one which would permit addressing the most important intellectual challenges of our field within a budget with only modest increases.

The FY1986 Presidential budget implies very severe constraints on nuclear physics, in plotting this budget on Figure 1 it is likely to be the lowest level of support, relative to the Gross National Product, in over 20 years. This level will likely result in a further decrease in the utilization of existing facilities. Relief in operating and especially equipment funds is needed. As we approach the new frontiers of our science the experimental approaches must generally become more complex, and equipment needs are increasingly pressing on our resources.

In commenting on the stringencies of the budget I do not want to give the impression that our field is stagnant. The ongoing program with present facilities is producing new knowledge and exciting fresh insights are emerging. Some modest new facilities and new techniques are being implemented and small improvements and upgrades are being carried out to existing facilities.

At lower energies, improvements are under way to the accelerators at the University of Washington and at Yale, major components of the university-based facilities of our science. At somewhat higher energy a heavy-ion accelerator facility utilizing a new superconducting technology for the first time is about to be completed on schedule and on budget at Argonne National Laboratory, the ATLAS accelerator shown in Figure 2. The science at these energies concerns itself with the properties of the atomic nucleus. Rapidly rotating but otherwise cold nuclei, as shown schematically in Figure 3, are of particular interest and are being studied with a variety of techniques. An important new device is the Berkeley Compton-suppressed Ge detector array shown in Figure 4.

At somewhat higher energies in data shown in Figure 5, we have the surprising result that the collision of two heavy nuclei produces pions (the particles whose exchange is largely responsible for the nuclear force) even when the ions have very low velocities. Totally unexpected was the magnitude of this pion yield, especially at the lowest energy where the yield was recently measured using the Oak Ridge Holifield facility. It tells us that there must be a number of protons and neutrons (20 or more) that act together in giving up most of their energy to create a single pion, implying a degree of cooperation and coherence among the interacting nucleons that was entirely unimagined.

Nuclear physicists have stated repeatedly over the past several years the important science that can come from electromagnetic studies with continuous electron beams. At lower energies pulsed beams of electrons are being used at the MIT Bates Laboratory to provide information on nuclear shapes in remarkable detail, as may be seen in Figure 6. In order to begin some very limited measurements at higher energies with pulsed beams, before the 4-GeV continuous beam electron accelerator is built, a modest improvement project at the high-energy physics laboratory at Stanford (SLAC) was completed a few months ago (Figure 7) and will allow a limited start to be made on certain measurements with electromagnetic probes.

The highest energy heavy-ion beams now available anywhere are from the Berkeley Bevalac and recent results, summarized in Figure 8, indicate that the nuclear equation of state indeed does behave in the way that was predicted theoretically. It should be noted that the same theory predicts that nuclear matter at much higher energies will undergo a phase transition to an entirely new form of matter, a quark-gluon plasma. The next step in reaching for higher energies is being taken at Brookhaven, where an injection line is under construction to the AGS accelerator, shown in Figure 9. This is to provide beams of oxygen and sulfur with energies higher than those at Berkeley, but still below those where the phase transition is expected to occur. The completion of this project is eagerly awaited.

THE REVIEW OF THE SCIENTIFIC PRIORITY FOR THE 4-GEV ELECTRON ACCELERATOR

During the summer of 1984 NSAC was asked by the Department of Energy and the National Science Foundation, and at the request of the Director of the Office of Science and Technology Policy, Dr. George Keyworth, to reexamine the scientific justification of a 4-GeV electron accelerator for nuclear physics. A subcommittee to NSAC was formed which reexamined the relevant issues and then strongly reaffirmed the nuclear science community's commitment to electromagnetic studies as a major focus for addressing a broad range of fundamental open questions in nuclear physics and its interface with QCD --

the theory expressing our present best understanding of elementary particles in terms of quarks and gluons.

The subcommittee endorsed the prior 1983 recommendation of NSAC that the first priority major construction project for nuclear physics be a 4-GeV electron accelerator. It emphasized its view that this facility is to be the major component of a structured program of electromagnetic research which should provide the U.S. with world-leading capabilities for exploring atomic nuclei and particularly the effects of nucleon substructure. The subcommittee also reinforced the recommendation of the 1983 NSAC study for a relativistic heavy-ion collider as the next major construction project complementary to the electron accelerator.

REVIEW OF THE 1983 LONG RANGE PLAN FOR NUCLEAR SCIENCE

Later in 1984 NSAC was asked to review the 1983 Long Range Plan and take into account recent developments. Responding to that request, a study was carried out, and in the resultant report of December 1984 the scientific priorities and recommendations of that plan were substantively reaffirmed. The report stressed five points, all of them reiterations of components of the Long Range Plan.

(a) The continuing base program in nuclear science, with existing facilities and those now under construction faces vital challenges and opportunities. After a decade of severe fiscal constraints it needs increased operating and equipment funds; a ten percent one-time real increase was recommended in the 1983 Long Range Plan and is still needed. Without a vigorous program of ongoing research the ideas, the knowledge, and the training of scientists necessary, both to our society and to future endeavors in the quest for knowledge, will not be forthcoming.

(b) The first priority for major construction is the 4-GeV electron accelerator. NSAC expressed concern about the delays which had already occurred in that project and about the management problems which had not yet been resolved. As part of a structured program of electromagnetic research modest improvements to existing lower energy facilities were foreseen to provide 300 MeV and 1-GeV continuous electron beam capabilities. NSAC urged prompt consideration of proposals for such upgrades.

It should be said here, that since the time NSAC expressed its concern about the 4-GeV (CEBAF) project a search committee was convened, chaired by Dr. Edward Knapp, and this committee recommended a strong candidate for Director of the CEBAF project. I understand that the implementation of this recommendation is proceeding rapidly. This would go a long way towards resolving the management problems perceived by NSAC.

(c) The major new scientific opportunity identified in the 1983 Long Range Plan was in a relativistic heavy-ion collider, to address a frontier area inaccessible by other means, exploring what we believe will be entirely new forms of matter. This is seen as the major construction project complementary to the electron accelerator. A start on the process of examining and evaluating proposed designs of facilities and of the R&D required before construction can be undertaken is needed as soon as possible.

(d) The importance of scientific opportunities provided by high-energy high-intensity proton beams is pointed out for the more distant future beyond the current Long Range Plan.

(e) The importance of graduate student training in the United States is stressed, for nuclear science, as well as for physical sciences generally.

The priorities of our field have thus been consistent over the past several years as designs have been refined and as new research results have illuminated the physics questions of greatest interest. We see major scientific opportunities ahead, but the resources available to address them remain severely constrained. Funds for operating and upgrading existing facilities are shrinking and the construction of new facilities is further delayed. Yet the challenge and the excitement of opportunities for new knowledge are a powerful driving force and if our endeavor is to remain healthy, if we are to retain first-rate scientists and attract the best young people into careers in science then we must get on with the task of exploring the frontiers of knowledge that are on the verge of being accessible.

At a recent meeting of NSAC on February 14 and 15 we were delighted to hear and see the evidence that the activities associated with the planning and designing of new facilities is proceeding vigorously. As was said in our Long Range Plan and the reviews that were carried out during the past year, it will take several elements within a structured program to meet the substantial challenges facing us now.

Unfortunately, under the FY1986 budget submission we are not able to make a start on these and even R&D activities leading up to eventual new facilities, such as the relativistic heavy-ion collider, will remain unfunded. In order to maintain the enthusiastic momentum that has been building over the past several years -- as new frontiers in nuclear physics have emerged from ongoing research -- it is essential that during this period of budgetary retrenchment we, at the very least, maintain active R&D programs directed towards the major complementary facilities of the 4-GeV electron accelerator and the relativistic heavy-ion collider. These two facilities will be crucial in providing for the U.S. a unique position of leadership within the international scientific community and will allow us to continue our vital role in the development of the new knowledge and the new talent essential to the future of the nation.

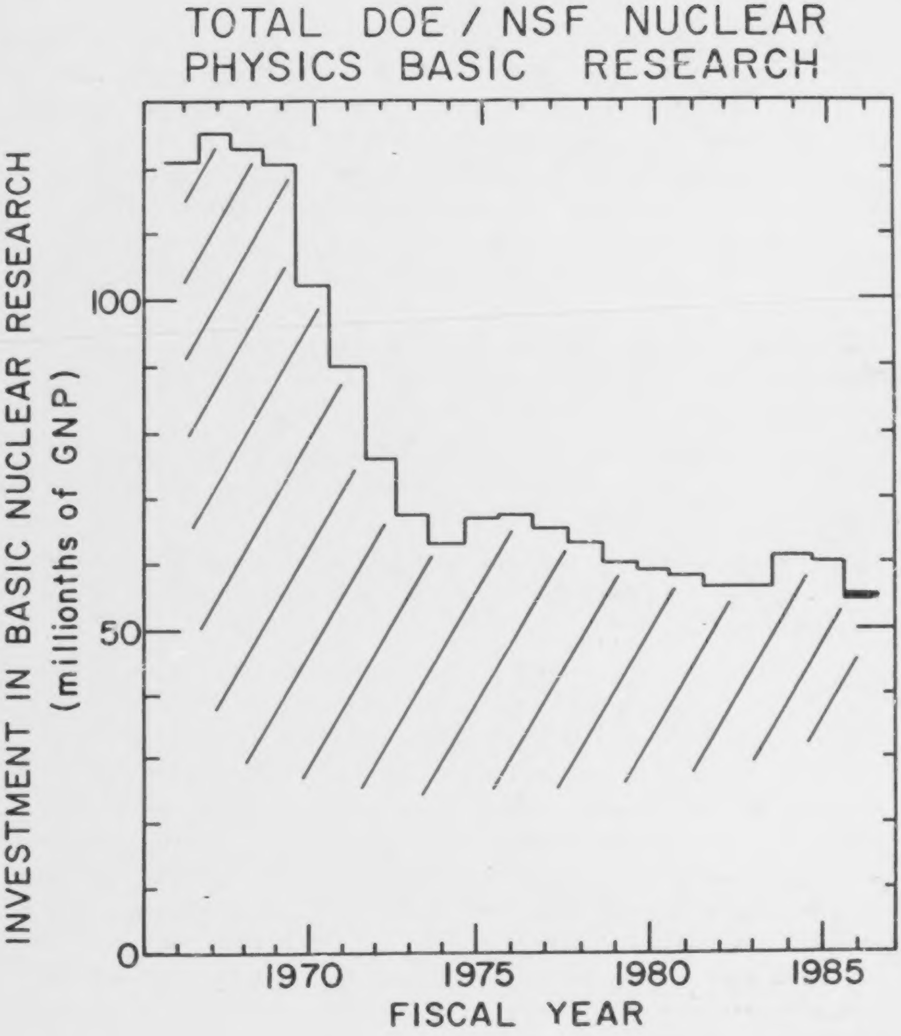


Figure 1 Total federal budgets for basic nuclear research.

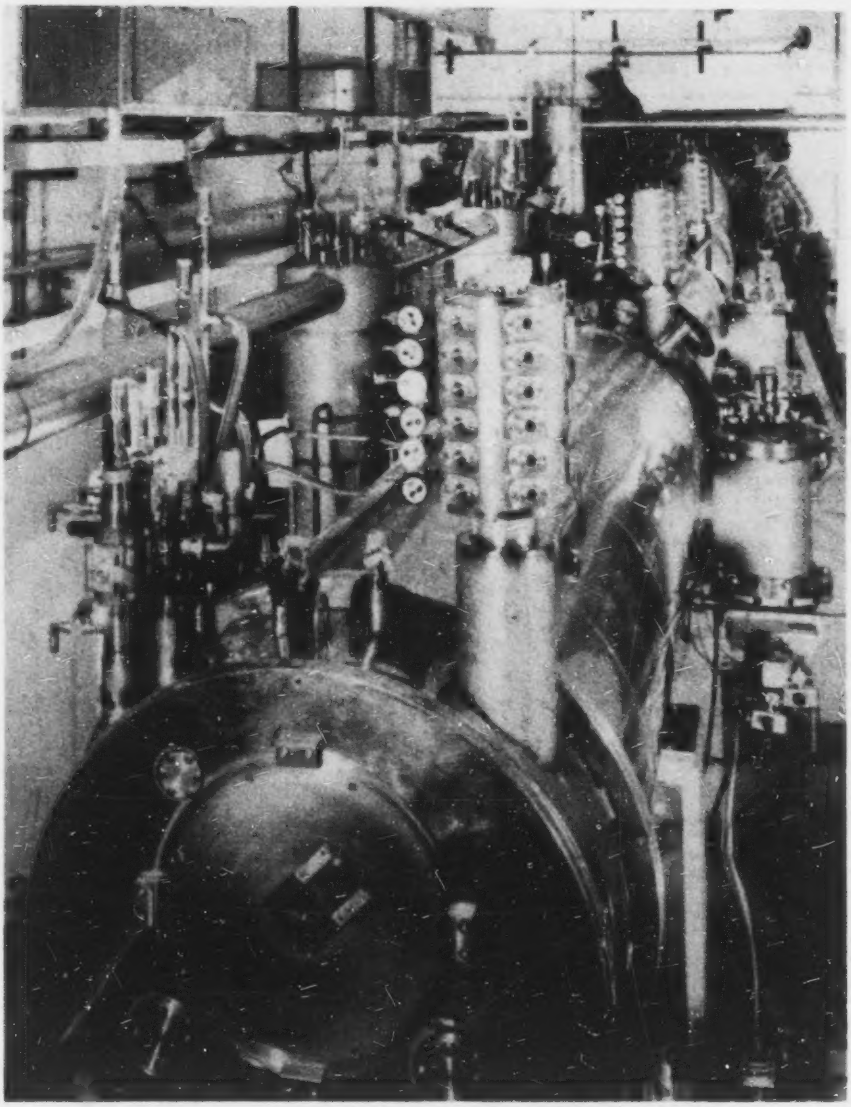
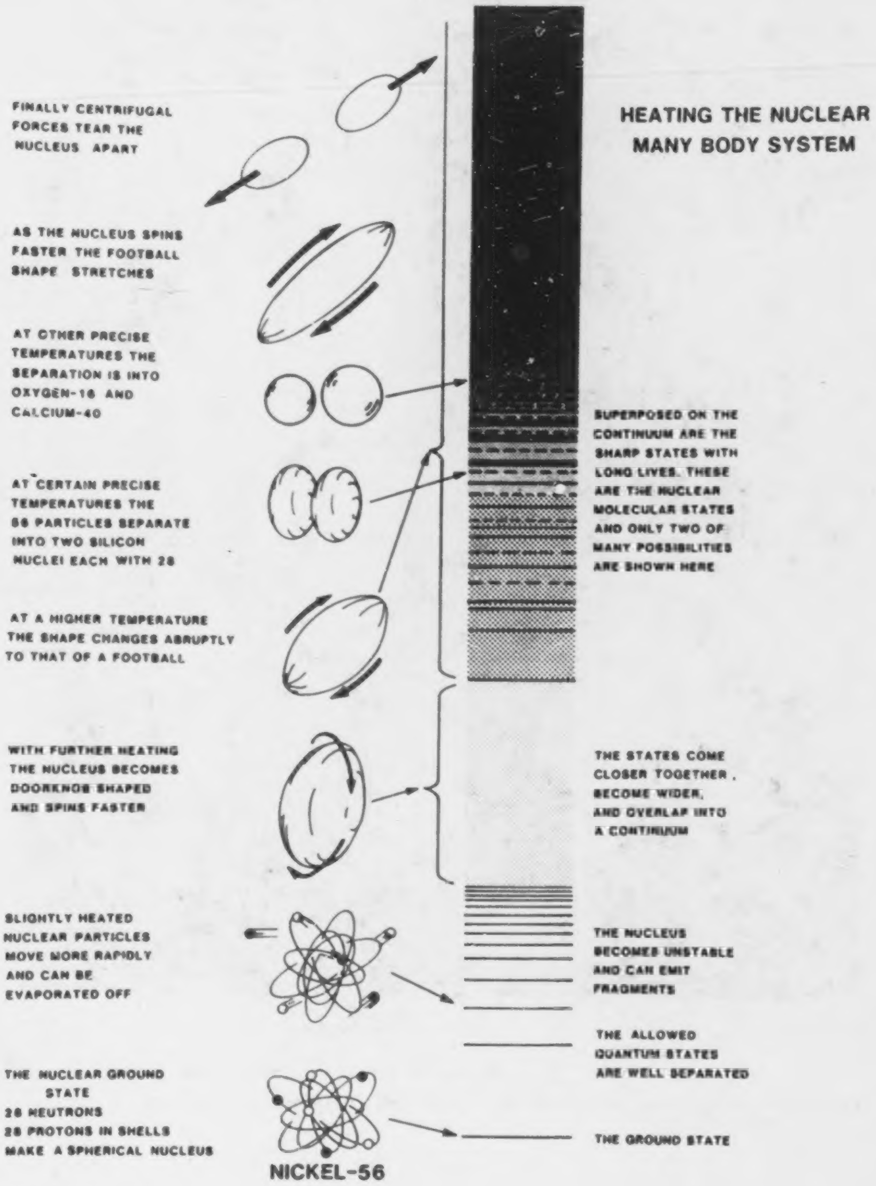


Figure 2 Assembly of ATLAS, a unique heavy-ion accelerator based on new superconducting technology developed, at Argonne National Laboratory.

Figure 3 Schematic of the evolution of a nucleus, that has been extensively studied at the Yale Nuclear Structure Laboratory, as a function of increasingly rapid rotation.


HEATING THE NUCLEAR MANY BODY SYSTEM
FINALLY CENTRIFUGAL FORCES TEAR THE NUCLEUS APART
AS THE NUCLEUS SPINS FASTER THE FOOTBALL SHAPE STRETCHES
AT OTHER PRECISE TEMPERATURES THE SEPARATION IS INTO OXYGEN-16 AND CALCIUM-40
AT CERTAIN PRECISE TEMPERATURES THE 56 PARTICLES SEPARATE INTO TWO SILICON NUCLEI EACH WITH 28
SUPERPOSED ON THE CONTINUUM ARE THE SHARP STATES WITH LONG LIVES. THESE ARE THE NUCLEAR MOLECULAR STATES AND ONLY TWO OF MANY POSSIBILITIES ARE SHOWN HERE
AT A HIGHER TEMPERATURE THE SHAPE CHANGES ABRUPTLY TO THAT OF A FOOTBALL
WITH FURTHER HEATING THE NUCLEUS BECOMES DOORKNOB SHAPED AND SPINS FASTER
THE STATES COME CLOSER TOGETHER, BECOME WIDER, AND OVERLAP INTO A CONTINUUM
SLIGHTLY HEATED NUCLEAR PARTICLES MOVE MORE RAPIDLY AND CAN BE EVAPORATED OFF
THE NUCLEUS BECOMES UNSTABLE AND CAN EMIT FRAGMENTS
THE ALLOWED QUANTUM STATES ARE WELL SEPARATED
THE NUCLEAR GROUND STATE 28 NEUTRONS 28 PROTONS IN SHELLS MAKE A SPHERICAL NUCLEUS
THE GROUND STATE
NICKEL-56

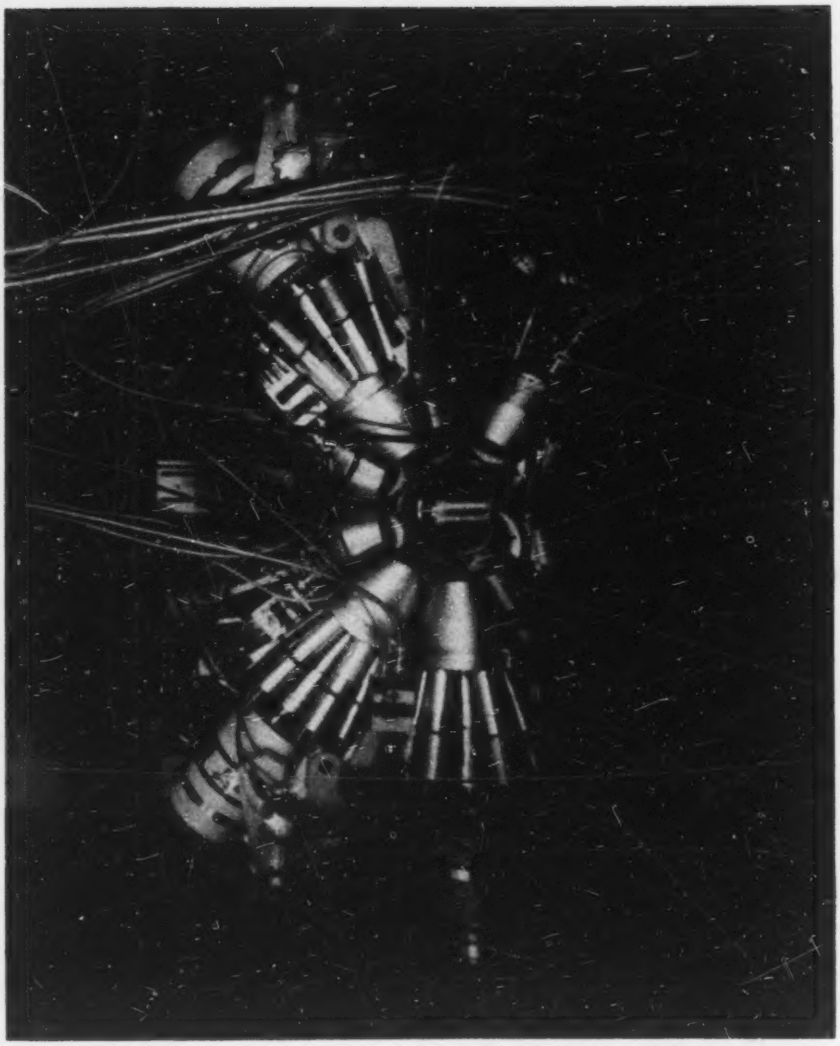


Figure 4 The new Compton-suppressed gamma-detector array 'HERA' at the Lawrence Berkeley Laboratory.

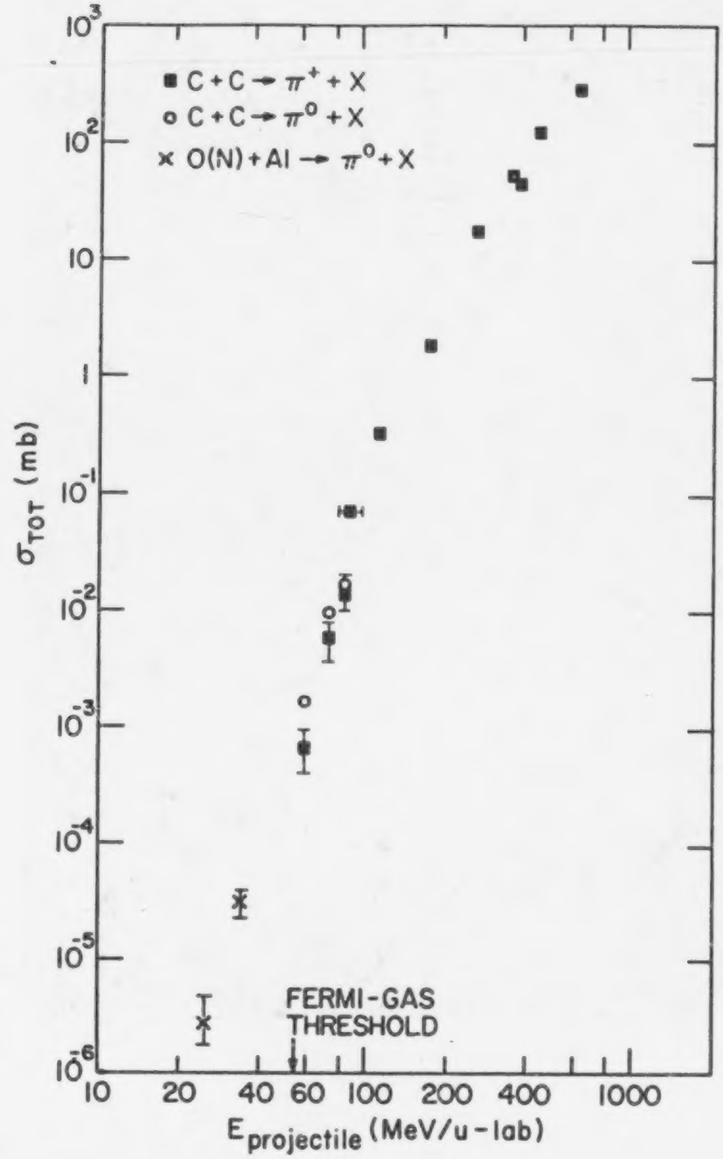
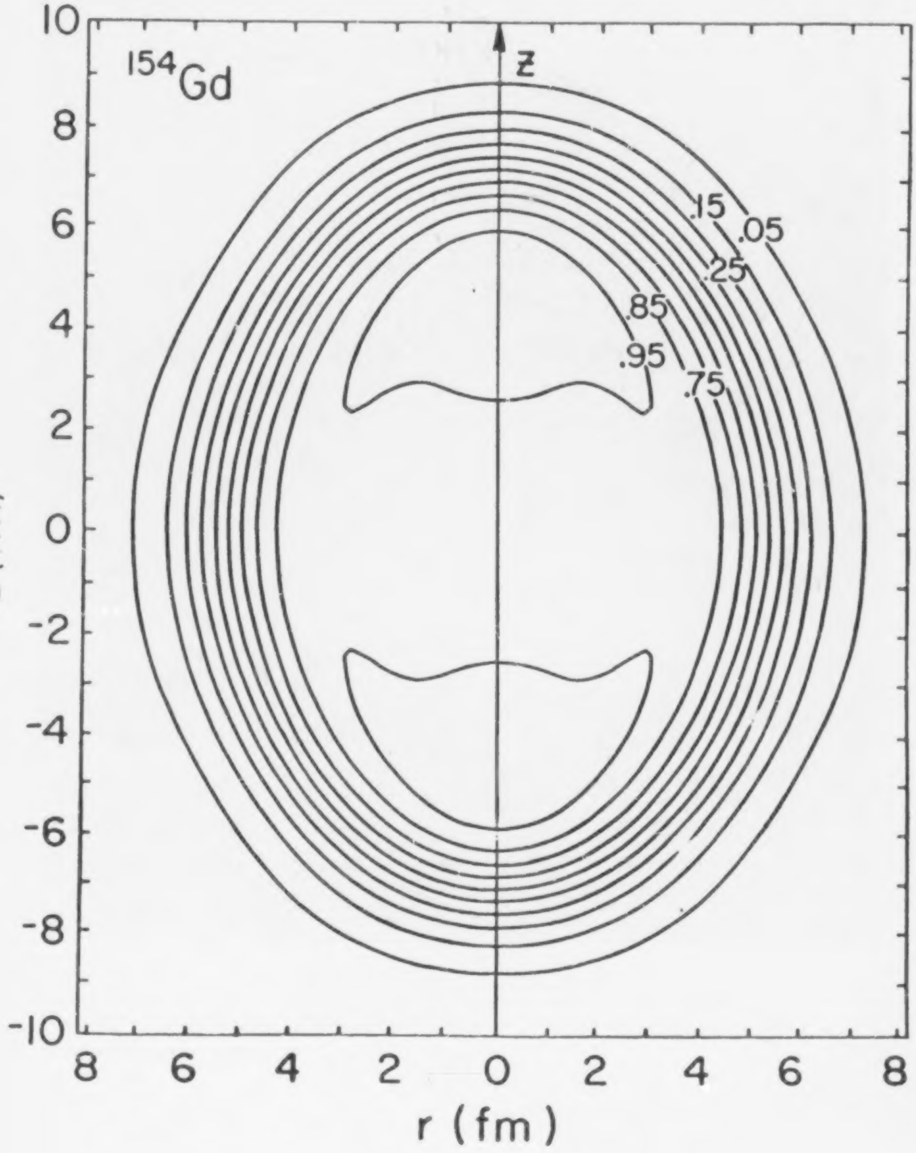


Figure 5 Pion production from the collision between low-velocity heavy ions. The data shown were obtained at a number of laboratories in the U.S. and Europe including Oak Ridge National Laboratory.

Figure 6 The charge density of a spheroidally deformed nucleus deduced from precision electron scattering experiments at the MIT Bates Laboratory.



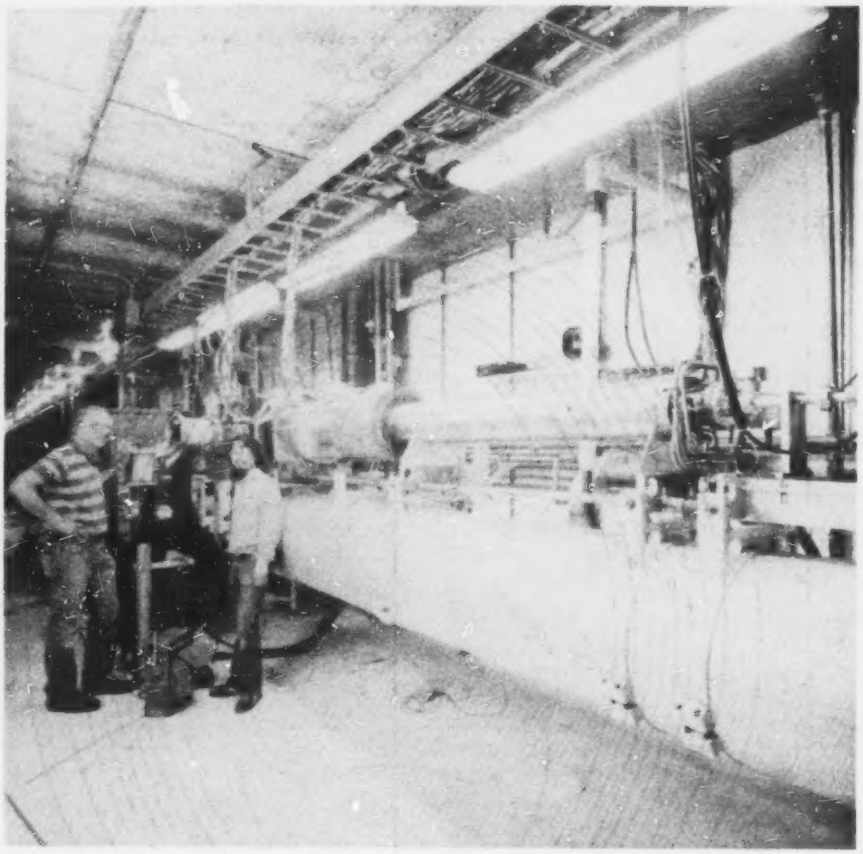


Figure 7 The new 'nuclear physics' electron injector at the Stanford Linear Accelerator Laboratory at endstation A.

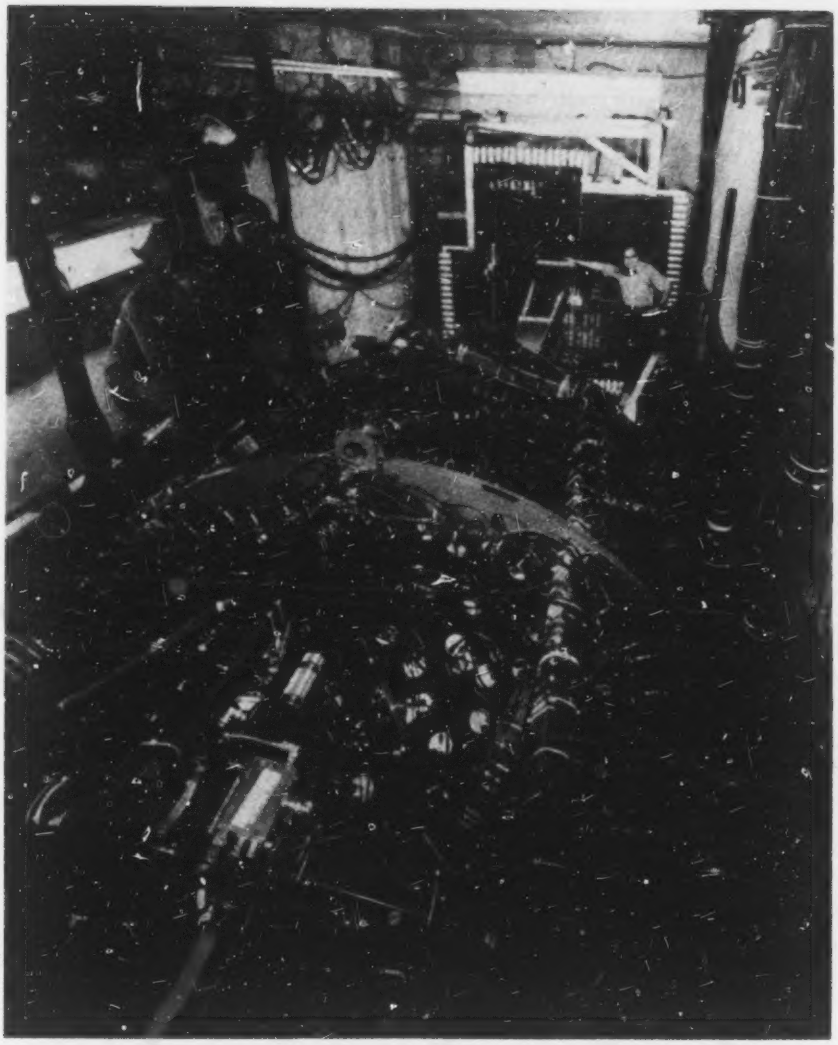


Figure 8 The Berkeley 'plastic ball' used in key experiments to study the collision between relativistic heavy ions.

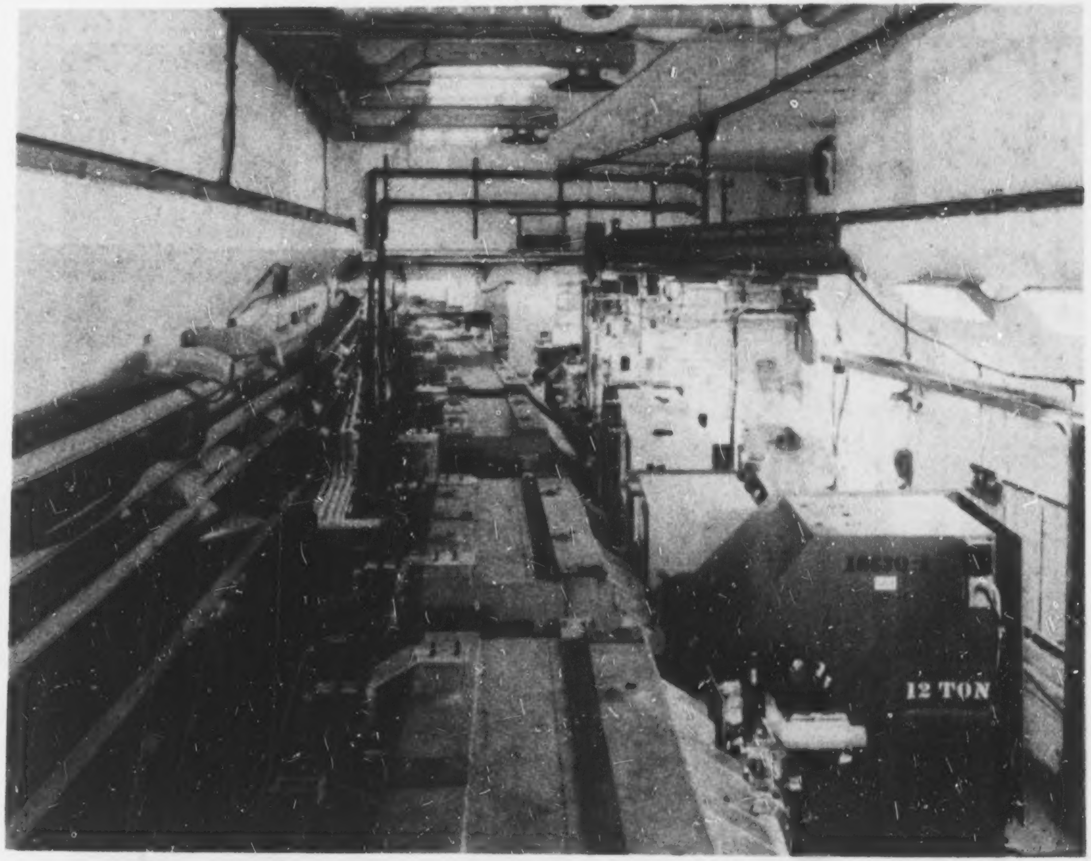


Figure 9 A view of the AGS tunnel at Brookhaven National Laboratory showing a part of the accelerator with the beam line where the 15 GeV/u oxygen beam will be extracted when the heavy-ion injector is completed.

September 27, 1984
File: 84-f-vogt.901,
NSAC/final

Report of the NSAC Ad Hoc Subcommittee on a 4 GeV CW Electron Accelerator for Nuclear Physics

1. Recommendation and Summary

The subcommittee unanimously reaffirms the nuclear science community's commitment to CW electromagnetic studies as a major focus for addressing a broad range of fundamental open questions in nuclear physics and its interface with QCD. The subcommittee endorses the recommendation that the first priority major construction project for nuclear physics be a 4 GeV CW electron accelerator. We view this facility as the major component of a structured electromagnetic research program providing world-leading new capabilities for exploring atomic nuclei, particularly the effects of nucleon substructure.

Exploration of the interface between nuclear physics and QCD necessarily also involves complementary studies, including those with relativistic heavy ions recommended as the aim of the second major construction project in the 1983 Long Range Plan. The 4 GeV electron accelerator, the electromagnetic program, and the relativistic heavy ion studies are important components of the whole U.S. program for future frontier studies in nuclear science.

2. Introduction

In the light of the very recent decision of the Congress to "defer without prejudice the construction of the Continuous Electron Beam Accelerator Facility", Dr. George Keyworth, Director of the Office of Science and Technology Policy requested advice on the scientific justification of a 4 GeV electron accelerator for nuclear physics. The following subcommittee of the DOE/NSF Nuclear Science Advisory Committee was formed for this purpose: Prof. Gordon Baym* (Univ. of Illinois), Prof. D. Allan Bromley* (Yale Univ.), Prof. Glennys Farrar (Rutgers Univ.), Prof. Steven Koonin (California Institute of Technology), Prof. John Negele (Massachusetts Institute of Technology), Prof. John Schiffer* (Argonne National Laboratory and University of Chicago), Prof. Ingo Sick* (Univ. of Basel), Prof. Erich Vogt*, Chairman (Univ. of British Columbia), Prof. Dirk Walecka (Stanford Univ.). The asterisks indicate those members of the subcommittee who are also members of NSAC.

The following was the charge to the subcommittee:

> In 1982 the DOE/NSF Nuclear Science Advisory Committee endorsed the report of its Subcommittee on Electromagnetic Interactions and subsequently, in 1983, it endorsed the recommendation of its Panel

> Electron Accelerator Facilities, that a 4 GeV continuous beam electron accelerator be constructed. The primary scientific justification for 4 GeV was the importance of the studies to be conducted on the developing interface between nuclear physics and QCD - the theory expressing our present best understanding of elementary particles in terms of a quark-gluon substructure. In the face of our latest scientific understanding, is the original recommendation, to build a 4 GeV CW electron accelerator still the most effective strategy for nuclear physics and, especially, for exploring this important frontier of the field?

The subcommittee met to begin its deliberations in Washington, D.C. on July 13 and 14, 1984. It also met at that time with Dr. Keyworth and with Dr. Alvin Trivelpiece, Director of Energy Research, Department of Energy. As a result of these discussions with Dr. Keyworth and Dr. Trivelpiece, it was clear to the subcommittee that it was intended to concentrate on the physics of a 4 GeV facility and not to address other matters, such as the management or the site of the facility, which are the direct responsibility of DOE and OSTP. In the subcommittee's view these other matters are indeed important and our recommendation in support of a 4 GeV facility is based on the premise that this facility will have the outstanding management, scientific leadership, and technical competence which are needed for its timely completion and the realization of its potential for world leadership in the field. The subcommittee's recommendation is also based on the assumption that the 4 GeV facility can be constructed and put into operation within the fiscal structure set forth in the report of the Bromley Panel (NSAC Panel on Electron Accelerator Facilities, 1983). The subcommittee was requested to report to NSAC as soon as possible. Taking into account the charge, the time interval for response, and the previous history of NSAC decisions, the subcommittee considered the dominant question to be the scientific justification for a 4 GeV CW electron accelerator and particularly whether or not recent developments in our understanding of the relevant physics might have significant impact on its scientific justification.

The subcommittee met to continue its deliberations in Washington, D.C. on August 4th, in Chicago on September 14th, and in Washington on September 23rd and 24th, 1984. Before reaching its conclusions, it discussed the frontiers of electromagnetic interactions and nuclear physics with reference to the Barnes Report (NSAC Subcommittee on Electromagnetic Interactions, 1982) and the Bromley Report. It also discussed extensively the questions raised by recent theoretical developments, particularly in regard to the interface with QCD. Further, it reconsidered, in the light of the physics opportunities, the energy choice and duty factor of an electron accelerator and its position within a structured system of electron facilities and within the other components of the 1983 NSAC Long Range Plan for nuclear physics. Its assessment of these matters is given below.

3. Electromagnetic Interactions and Nuclear Physics

Recommendations of the nuclear science community over the last decade have recognized consistently that electron beams are the tool of choice for a significant fraction of the rapidly evolving field of nuclear physics. The electron probe is particularly powerful for nuclear physics because it is so clean. The electromagnetic force is well understood - in terms of quantum electrodynamics (QED). Further, electromagnetic probes are among those which have great kinematic versatility: the momentum and the energy imparted to the target can be varied independently. Beams with very low emittance, and detection techniques developed for attaining excellent energy resolution, have led to high precision. For nuclear physics the electron has been particularly effective and versatile as a probe because it interacts not only with the nuclear charge density but also with convection currents and the magnetization density. In sum, electron scattering provides an unambiguous determination of the electromagnetic structure of atomic nuclei; our understanding of nuclei is then advanced by interpreting this structure in terms of the particular degrees of freedom relevant at various distance scales, as discussed in Sec. 4.

What has been lacking heretofore in nuclear physics with electron beams is accelerators, at appropriate energies, with high duty factor. The duty factors have typically been 0.01 or less. Continuous beams will extend the advantages of electron probes to a wide range of new experiments involving the detection of particles in coincidence. It was the advent of the technology for such continuous beam electron accelerators in the GeV range which, together with the development of the physics, led to the scientific momentum for a CW electron accelerator at several GeV.

Beginning with the Friedlander Report (1976) in pre-NSAC days and subsequently in the NSAC reports of 1977, 1979, 1982 and 1983 a full account has been given of the development of recent electron accelerator technology and of nuclear science with such machines - including their impact on nuclear structure and dynamics, which we summarize here. Their potential for exploring the QCD interface is discussed in the next section.

The most precise knowledge we have of nuclear structure comes from single-arm electron scattering experiments. This includes the shape and radial distribution of the charge density, the distribution of ground state magnetization density, the microscopic spatial distributions of transition densities, the properties of giant resonances, the structure of collective and high-spin magnetic excitations, the presence of meson exchange currents, and the structure of single-particle and single-hole states in nuclei. Going beyond these the Barnes Report describes the rich nuclear structure which can be studied by CW electron facilities spanning the energy range from a few hundred MeV to several GeV: the complete characterization of nuclear multipole amplitudes including measurement of spin observables, the study of deep-lying hole states through nucleon knockout reactions, the production of delta particles and their propagation in the nuclear medium, and the use of two-nucleon knockout as a probe of short-range correlations in the nucleus.

The study of nuclear structure with electromagnetic probes - and, indeed with other probes as well - promises to be a fertile field of science far into the future. The nuclear many-body system has many important aspects and many separate frontiers while at the same time retaining a fundamental unity. It is because of the special nature of our subcommittee's charge that we emphasize electromagnetic probes and, more specially in the next section, the use of electromagnetic probes for issues of the QCD interface.

4. Electromagnetic Interactions and QCD

If one asks how to describe the nucleus in terms of the behavior of its constituents, the answer changes with the spatial resolution of the probe. At distances greater than about 1 fermi, which can be resolved with electron beams of a few hundred MeV, one has the familiar picture of neutrons and protons (nucleons) undergoing individual and collective motion in the nucleus. With somewhat higher energies, approaching 1 GeV, the contributions of mesons and nucleon excited states to the electromagnetic structure of the nucleus can become important.

As one increases the energy still further, distances small compared to the size of the nucleon itself become accessible and a more explicit account must be taken of the fundamental structure of nucleons as composites of colored quarks interacting through gluon exchange. At this spatial resolution one expects observable effects arising from the overlap of extended nucleons within the nucleus, and the physics of confinement becomes relevant. In this regime QCD is non-perturbative (it cannot be handled by the standard approximation technique of perturbation theory) and the analysis of such effects is correspondingly difficult. At substantially higher energies (tens or hundreds of GeV) one begins to enter the asymptotic regime in which perturbative QCD is applicable and greatly simplifies the analysis of experiments. The analysis of the EMC effect, in which high energy electron or muon scattering measures the difference between the distribution of quarks within a free nucleon and those inside a nucleus, beautifully illustrates this application of perturbative QCD.

The interface with QCD is a fundamental and rapidly evolving frontier of nuclear science. Based on our current understanding, we distinguish two complementary types of electromagnetic studies of this interface, namely, those involving subasymptotic physics at moderate energies and those involving asymptotic physics at high energy.

In the subasymptotic regime for the nucleus we have at present no precise framework or language to describe the physics when nucleons overlap. We use here terms such as "hadronic physics" when we wish to refer to the possible internal excitation of nucleons, or to meson degrees of freedom, and "confinement physics" to refer to the possibility that the quark constituents of different nucleons overlap in their motion. At modest bombarding energies, in the vicinity of a GeV or more, one can produce the lowest excited state of the nucleon - the delta particle - and begin the study of its interactions in the nucleus. A number of very important hadronic studies are accessible only with several GeV electron energy and high intensity. These include better determination of nucleon and few-nucleon form factors measured to higher momentum transfer, and studies of higher excited states of the nucleon in the nucleus.

The confinement issues are of great importance for all of physics, and nuclei are unique laboratories for their study. The initial focus will likely be on simple few-nucleon systems, where new aspects of nucleon substructure might first be revealed. To find such aspects one would like to go to excitation energies above 1 GeV which marks the region where sharp nucleon resonances in the nucleon response function disappear and the behavior is dominated by the broad response of point-like constituents.

Addressing the problem from a different point of view, one should also search for physics at the interface in terms of the concept of "degrees of freedom" of the nuclear many-body system. Experience with other quantum many-body systems indicates that there may be opportunities here for discovering new physical phenomena. Systems of fermions, such as electrons in a conductor, liquid ^{3}He and, indeed, atomic nuclei display interesting quasiparticle structure in strongly interacting regimes. More generally, a knowledge of the forces, even when they are reasonably tractable (as in the case of QED) does not necessarily allow one to predict fascinating new physics. For example, in the absence of experimental discovery, superconductivity would not have emerged from our theoretical understanding of the underlying electromagnetic interactions in the form of QED. The search for new nuclear degrees of freedom and the relationship of nucleon-meson degrees of freedom to quark-gluon degrees of freedom in nuclei is one of the most challenging and fundamental questions of physics, which must be explored with facilities spanning both the subasymptotic and asymptotic regimes.

Studies in the range of tens to hundreds of GeV can exploit the simplicity of asymptotic QCD to determine precisely defined properties of quark distributions in nuclei. Indeed, the EMC studies mentioned above have given tantalizing hints of new effects arising when quarks are embedded in nuclei rather than in isolated nucleons. Further studies carefully separating longitudinal and transverse contributions, isolating the most important corrections to the asymptotic contribution, exploring isospin dependence, resolving specific final products, and making comparisons with neutrino scattering offer great promise for exploring the interface of nuclear physics with QCD.

In addressing developments in our scientific understanding during the past year which are germane to the physics of a 4 GeV electron accelerator, it is particularly relevant to consider the applicability of asymptotic freedom. Some have hoped that the simplifications of perturbative QCD might be brought to bear on exclusive 4 GeV electron nucleon and electron-nucleus scattering. This optimism was not widely accepted, and indeed, the consensus of the subcommittee is that fully asymptotic predictions of QCD are unlikely to be applicable to exclusive processes at these energies.

> The theoretical progress of the past year properly reemphasizes that the scientific interest at the QCD interface of an electron accelerator in this energy regime rests in the hadronic and confinement issues of QCD rather than in asymptotic freedom; most investigations will focus on the subasymptotic domain of QCD, on the properties of interacting quarks, and on the mechanism leading to confinement.

5. The Choice of Energy and Duty Factor

The accelerator of choice must have a high duty factor - it must be CW - to perform a wide variety of coincidence experiments. Although substantial progress will have been made on single-arm electron scattering before such an accelerator is operating, experience with other nuclear probes and with other many-body systems has shown that measurement of the final state (even partially) is of vital importance in clarifying the dynamics. CW operation is crucial for the whole range of coincidence experiments with electron beams. Furthermore, high intensity (of the order of 200 microamperes) is crucial for providing the multiple beams required for a national multi-user facility. The subcommittee has no hesitation in strongly reaffirming the dominant importance of CW operation.

The precise energy range of the accelerator was the subject of considerable discussion within the subcommittee. The judgment about the best energy was similarly difficult for the earlier Barnes and Bromley subcommittees. This subcommittee unanimously agrees on the outstanding research program afforded at energies up to several GeV and the majority of the subcommittee supports the full 4 GeV capability. The physics begins to be accessible at a beam energy of about 2 GeV. There is no known sharp threshold for new physics above 2 GeV but one gains kinematic flexibility, which can increase both the rate at which experiments can be carried out and the information they provide. Our discussion concerned the scientific priority of the extra flexibility.

In assessing the priority to be given to the full energy, the subcommittee considered again the list of experiments and the kinematic diagrams the Barnes Panel provided in its report. Doing this we found that the physics dealing with nucleons, nucleon resonances and mesons either is or begins to be accessible by 2 GeV. This includes determination of nuclear and nucleon multipole amplitudes, the study of deep-lying hole states, the nucleon spectral function in nuclei, two-body correlation functions through one and two nucleon knockout, and the study of pion and delta propagation in the nuclear medium through coincidence experiments. Some significant studies of few-nucleon systems can also be undertaken at 2 GeV, as well as a beginning of the study of hypernuclei above the threshold for their production. The spatial resolution accessible with 2 GeV electron beams is smaller than the size of the intrinsic structure of nucleons, so that new aspects of nucleon substructure and the physics of confinement should begin to be accessible. Important tests of fundamental symmetries can be performed below 2 GeV. The single-arm deep inelastic studies of complex nuclei cited by the Barnes Panel are beginning to be explored at NPAS (SLAC), but the coincidence studies which that panel emphasized must await CW beams. In sum, a significant part of the program of studies outlined in the Barnes report could be carried out with a 2 GeV CW facility.

The increased kinematic flexibility of a 4 GeV electron beam, relative to 2 GeV, can be exploited to probe smaller spatial scales and larger energy losses. In terms of spatial scales, the extra resolution (in the vicinity of 0.2 fermi) is important for the physics at the QCD frontier. The very small cross sections for electromagnetic processes mean that counting rates often determine the feasibility of a particular experiment. Higher energies allow higher counting rates by using a smaller scattering angle to achieve a given momentum transfer. The higher energy is desirable for the important separation of longitudinal and transverse response at large momentum transfers. A higher energy allows one to carry out two-baryon knockout under appropriate kinematic conditions to study the short range influence of the nuclear medium. Further, a significant program of hypernuclear physics carried out via the (e,e'K+) reaction with good energy resolution appears to require energies of at least 3 GeV. The higher counting rates at smaller working angles at 4 GeV may also be valuable for tests of fundamental symmetries, for example, measurement of parity violation in electron scattering from the nucleon, which will become practical with counting experiments once CW beams allow large solid angle detectors.

On the basis of the above considerations, the majority of our subcommittee supports the full 4 GeV energy for the CW electron facility, as did the earlier Barnes and Bromley subcommittees.

6. Structured Program of Electromagnetic Research

The 4 GeV electron accelerator must continue to be considered the central component of a structured program of electromagnetic research. The Bromley Report and NSAC made strong recommendations not only about the scientific priority of the 4 GeV accelerator, but also about the other elements of a world-leading national program which would be complementary to it. The program should include:

- Lower energy capabilities providing CW electron beams. A 1 GeV facility would be relatively inexpensive and would emphasize very high resolution. At still lower energies other CW facilities would, in turn, be complementary to such a 1 GeV facility. All of these lower energy facilities are likely to be the natural extension and continuation of presently operating facilities.

- Vigorous use of existing high energy facilities. These are beginning to be used now to address the implications of QCD for nuclei and should be used more extensively in the future. Prominent among the capabilities at high energy laboratories are the 20 GeV electron beam at SLAC and the 800 GeV muon beam soon to be completed at Fermilab. With these beams, the crucial exploration of nuclei in the regime of asymptotic QCD will be carried considerably beyond our present understanding, and we see such a set of measurements as an essential component of a structured program. The NPAS program is another example of utilizing capabilities at high energy laboratories, and is a forerunner of the full experimental program at the CW facility. Other opportunities should appear in the future with high energy accelerators and storage rings; it is important that these opportunities be pursued in a timely and judicious way.

- Increased general support of the whole nuclear physics research program, as outlined in the 1983 NSAC Long Range Plan. In recommending the CEBAF facility within the Long Range Plan, and in subsequent communications, NSAC stressed that the vitality and growth of the ongoing nuclear physics program required a one time real increase in operating funds, to be used for better utilization of facilities, development of instrumentation, training of young scientists, and support of user groups. While this recommendation cuts across the whole field of nuclear physics it is of special importance in discussing a new frontier area where such an increment is most likely to have a major scientific impact. We reassert this recommendation, from the perspective of our charge, very strongly.

7. Strategies for Exploring the Interface of Nuclear Physics and QCD

The charge to the subcommittee refers to the broad question of the most effective strategy for exploring an important new frontier, the developing interface between nuclear physics and QCD, with particular attention to the scientific justification for a CW electron accelerator of several GeV. We have answered by reaffirming this project as the first major construction project for nuclear physics, within a structured program of electromagnetic physics. Other projects related to the issues of nuclear physics and QCD must surely follow and indeed, the 1983 Nuclear Physics Long Range Plan identified a relativistic heavy-ion collider as the following major construction project.

Going beyond our dominant question, we turn here to the general question of exploring the interface of nuclear physics and QCD. The richness of QCD will give rise to a diversity of phenomena requiring study with a corresponding diversity of probes. As is clear from the Long Range Plan, effective exploration of the interface between nuclear physics and QCD necessarily involves, in addition to electromagnetic facilities, consideration of relativistic heavy ion collisions and of hadronic probes which address complementary fundamental aspects of this interface:

Electromagnetic probes have been utilized for decades to explore nucleons and nuclear structure. They are a highly-developed, well-understood tool whose further exploitation is motivated by the precision and interpretability they provide. As elaborated above, they explore two key aspects of the QCD interface, namely hadronic and confinement physics at several GeV and the asymptotic region at tens to hundreds of GeV. The knowledge of nuclear structure obtained with electromagnetic probes will continue to be a prerequisite for the interpretation of experiments with many other probes of nuclei.

Relativistic heavy ion collisions offer the opportunity for a major new complementary initiative, the exploration of an entirely uncharted regime: regions of high energy density and baryon density of sufficient spatial extent to produce new phases of matter - for example, the possible creation and study of a quark-gluon plasma.

Light hadronic probes (nucleons, pions, kaons, antinucleons, etc.) have the potential for exploring many other important aspects of the QCD interface. These probes could be provided by the primary and secondary beams of a high-intensity proton accelerator operating at several tens of GeV. Such a facility lies beyond the 1983 Long Range Plan.

In advising on the implementation of the 1983 Long Range Plan, NSAC will need to consider, in the context of the overall balance of nuclear science, the evolving possibilities for a full attack on the QCD issues as well as the various components and options of the electromagnetic program on which we have focussed. Such consideration by NSAC must continue to take account of the science opportunity and the cost effectiveness of each option and each approach.

8. Conclusions

The subcommittee reaffirms a 4 GeV CW electron facility as the first major construction project for nuclear physics. It did not arrive at this decision lightly, for nuclear physics is a broad and vital field with other important frontiers, which we have not addressed in this report. The 1983 Long Range Plan for nuclear physics was developed following consideration of the scientific priorities for the field. We concur with the overall balance for nuclear science outlined in that Plan.

The United States remains in a position for world leadership in electromagnetic research in nuclear science. Vigorous action on the whole program in this area is essential both for the strength of nuclear science in this country, and for maintaining this leadership position in the face of plans abroad for operating several CW electron accelerator facilities, in the vicinity of 1 GeV, within three to four years. Our report and recommendation are intended to promote that action.

REVIEW OF THE 1983 LONG RANGE PLAN FOR NUCLEAR SCIENCE
DOE/NSF Nuclear Science Advisory Committee
November, 1984

SUMMARY

At the request of the Department of Energy and the National Science Foundation the DOE/NSF Nuclear Science Advisory Committee has reviewed its 1983 Long Range Plan for Nuclear Science, taking into account the developments of the past year. The scientific priorities and recommendations of that Plan are reaffirmed.

1. Evolution of Plans for Nuclear Science

During the past decade, nuclear science -- the study of the nuclear many-particle system, its modes of motion and its response to a wide variety of external probes -- has incorporated important new ideas and achieved a new intellectual unity. It has been known for a long time that nuclei can be viewed on two levels, as systems of interacting nucleons (neutrons and protons) or as hadronic systems in which the role of excited nucleons and of mesons is taken into account explicitly. We now have begun, and see as a major opportunity for the future, the study of nuclei at a third and deeper level, in terms of the quark-gluon substructure and the many-body aspects of color confinement.

Long-range plans charting the future development of nuclear science were prepared in 1976, 1979, and 1983. As time passes, of course, relative priorities are modified and suggestions for the construction of new types of facilities are sharpened and brought to the point of specific proposals. The 1983 NSAC Long Range Plan and the view of nuclear science that it expresses are a natural continuation of earlier plans. We reaffirm the 1983 Long Range Plan, the view of nuclear science on which it is based and our belief in the scientific opportunities that it describes.

2. Broad Outline of the Long Range Plan

Nuclear physicists study the properties of atomic nuclei and nuclear matter, which form the overwhelming bulk of the world and the universe in which we live. These studies often require techniques that can probe or alter the state of a nucleus. With these probes the characteristic modes of nuclear excitation are sought, and then interpreted in terms of the degrees of freedom -- nucleonic, hadronic, or quark-gluon -- with which each mode is most naturally and simply described. With other more drastic probes the normal quiescent state of the nucleus may be disrupted and new classes of phenomena and even new phases of matter emerge. In addition, nuclear physics seeks to uncover otherwise inaccessible properties of fundamental interactions and symmetries, and to examine aspects of the basic theories of these interactions and their relation to the properties of many-body systems.

This undertaking is by its very nature complex and many-facetted. Phenomena must be studied with a variety of external probes over wide ranges of energy. The range of probes includes the electromagnetic (photons, electrons, muons), the weak (neutrinos), and the hadronic (pions, kaons, nucleons, antinucleons, light nuclei and heavy-ions). The information obtained from the different reactions induced by these projectiles is overlapping and complementary. As the physical questions to be addressed become deeper and more subtle the need for combined attacks by a wide variety of probes becomes more acute.

The long-range plans for nuclear science have consistently recognized the multi-facetted character of the techniques of experimental nuclear science and the need for balance among its components. The 1983 Long Range Plan, augmented by the 1984 report of the NSAC subcommittee on a 4-GeV electron accelerator -- the Vogt report -- may be summarized as follows in terms of a base program and of several major new opportunities involving large accelerator facilities.

(A). The continuing base research program in nuclear physics, with existing facilities and those now being constructed, faces vital challenges and opportunities. After a decade of fiscal neglect it needs increased operating and equipment funds to meet these challenges. Not only are the new opportunities and challenges important in their own right, but without a vigorous program of ongoing research the ideas, the knowledge, and the training of scientists necessary, both to our society whose technological sophistication is steadily increasing and to future endeavors in the quest for knowledge, will not be forthcoming.

The fabric of nuclear science depends upon input from many different but complementary areas. The 1983 Long Range Plan summarized the most important scientific questions facing the frontiers of our field with its present resources. For the science to be healthy and productive it is essential that the interdependence of small and large scale experimentation be recognized and that, in particular, support of the small not be lost in the move to new very large national facilities. It is essential, too, that the recommendation of the Long Range Plan that appropriate support for modest upgrading, modernization and expansion of the best and most essential of existing accelerators and non-accelerator facilities be supported. Nuclear physics also requires adequate computing facilities, a subject currently being examined by an ad hoc NSAC subcommittee.

The base program of nuclear science at the nation's universities and national laboratories with existing facilities is the core of our science from which new ideas, new endeavors, new contributions to society and the nation, a new generation of scientists and the future strength of our field will grow. Maintaining and strengthening what is excellent in this base program is an urgent need that we address in (3) below.

(B) As first priority for new major construction, NSAC endorsed in 1982, and again in 1983, a 4-GeV CW electron accelerator. The very recent Vogt report, endorsed and transmitted by NSAC, reviews the scientific questions that can be addressed and reaffirms the central role of such an accelerator and its status as the first priority for major new construction in nuclear physics.

Throughout the past decade electromagnetic interactions have been consistently identified as a powerful and uniquely clean means of addressing a broad range of fundamental open questions in nuclear physics. The Vogt report enumerates the main elements of a structured plan for electromagnetic physics especially in the leading frontier area of the interface between nuclear phenomena and the strong interaction and its characterization in the framework of quarks and gluons. With new electromagnetic probes nuclear physics will deal with the important questions concerning nucleons, nucleon resonances and mesons in nuclei in a broad array of experiments ranging from the exploration of deep-hole states in nuclei to the production and propagation of pions, kaons and deltas in the nuclear medium. For the important issue of nucleon substructure - to what extent and under what circumstances the nucleus should be viewed in terms of quarks and gluons rather than in terms of nucleons and mesons - there are two important regimes for experiments. For an accelerator with a maximum energy in the vicinity of 4 GeV the scientific interest rests in the hadronic issues (excited nucleons for example) and in the issues pertaining to the confinement of quarks in nucleons and mesons. At much higher energies other experiments of a structured program of electromagnetic studies will deal with the asymptotic issues of QCD, a regime in which the quark interactions are much simpler.

Recent theoretical developments have sharpened the questions and heightened the interest in the entire structured program of electromagnetic research. The Vogt report describes the whole range of scientific opportunity now open to the United States from the 4 GeV facility which remains the highest priority major construction project of nuclear physics, to more vigorous use of present facilities of high energy physics, and including modest improvements to provide continuous beam capabilities at existing electromagnetic facilities up to about 1 GeV. Proposals for such upgrades merit prompt consideration.

(C). A second major scientific opportunity was identified in the 1983 NSAC Long Range Plan in the construction and the research program with a relativistic heavy-ion collider. Specific proposals for such a facility are now before the funding agencies. A heavy-ion collider will present the opportunity for an important new initiative, the study of hadronic matter in the entirely uncharted regions of high energy density and baryon density over large spatial distances. Relativistic heavy-ion collisions are a necessary further approach to questions at the QCD interface, probing quark-gluon degrees of freedom in highly excited states of matter, and complementing studies by electron scattering. In addition, such collisions will permit fundamental studies of QCD and confinement questions, inaccessible by any other means. Most excitingly, it is predicted that qualitatively new phenomena will be uncovered, including a new phase of hadronic matter -- the "quark-gluon plasma". While the special conditions necessary for such matter may exist in the interiors of neutron stars and are thought to have existed during the first moments after the birth of the universe, the only means to produce and study such conditions in the laboratory is through relativistic heavy-ion collisions.

The program of heavy-ion research at lower energies with existing facilities was discussed in our 1983 report. The need for supporting the exciting research opportunities in this area, both at low energies, at the interface between nuclear structure and dynamics, and at energies approaching the pion production threshold and beyond, falls within the realm of the smaller existing facilities mentioned in (A) above.

(D). The Long Range Plan also stresses the importance of studies of the nucleus with light hadronic beams over a wide energy range. It calls for vigorous pursuit of this component of the scientific program by upgrading existing facilities and, for the future, points to the opportunities offered by a new facility with intense proton beams of about 10 GeV or more, one that will provide not only the higher-energy protons, but more intense pion, kaon, muon and antiproton beams. The production and propagation of pions, kaons, other mesons, and excited nucleons in nuclei is a rich field for exploration. Hypernuclei, nuclear systems of non-zero strangeness, can be studied in new ways with unprecedented accuracy. Secondary kaon and neutrino beams permit a wide variety of new tests of the minimal standard model which includes the very successful theory of the electroweak interaction. Finally, the use of high-energy hadronic probes will be an important complement to the high-energy electron and muon studies. In particular, since only hadrons interact with gluons and since electrons and muons are color blind, high energy hadronic probes are needed for a full study of the QCD interface.

(E). The 1983 NSAC Long Range Plan expressed concern at the declining numbers of graduate students in the physical sciences generally and in nuclear physics in particular. It is gratifying to note that the most recent surveys indicate that the number of students in the nuclear sciences is increasing. The exciting new opportunities in nuclear physics now and on its near term horizon are playing a role in this changing trend. In spite of this very recent increase, the number of fresh Ph.D's being trained in nuclear science is still insufficient to meet future demands of society, industry and government, and of the science itself. Efforts need to be continued to correct this insufficiency and, in particular, the importance of attracting high caliber graduate students and of providing the best possible training in nuclear science should be given prominent consideration in decisions on new facilities.

3. Implementation of the Long Range Plan

The major national nuclear science accelerator facilities presently are operating at a level of utilization that generally is lower than 60%. This is below the level we view as the minimum consistent with reasonable progress in the core program of nuclear science and does not allow prior investments in these facilities to provide the appropriate scientific returns to the nation. In a letter dated April 29, 1983, which was reemphasized in the 1983

Long Range Plan for Nuclear Science, we recommended a $20 million incremental adjustment in operations and equipment funds for the ongoing research program. We give the highest immediate priority to this $20 million increment in operating and equipment funds to restore the level of utilization of existing facilities, including improved instrumentation and programs to encourage and strengthen user groups and young investigators.

We see a major electromagnetic facility as having the highest priority for the construction of a large facility and a relativistic heavy-ion collider complementing it in an area which presents a related important opportunity. Specific recommendations for a new high-intensity multi-GeV proton facility lie beyond the current Long Range Plan. Nevertheless such a facility will have to be at the forefront of future planning for our field. As the facility requirements of our science become larger and more extensive, increasing attention will also have to be paid to international participation and cooperation, especially in connection with the major facilities considered here.

The Long Range Plan for nuclear science, developed and adapted over the past decade, and presented most recently in the 1983 NSAC report, is discussed above. It stresses the importance of increased support for the ongoing program of nuclear research and calls for new construction of major facilities. The steady upgrade of the best and most essential of present facilities should continue as scientific and technical opportunities present themselves at roughly the pace foreseen in the 1983 Long Range Plan. Maintenance of the momentum, progress, and vitality of nuclear physics requires the implementation of this Plan to proceed without periods of stagnation. We recognize that the framework of purely scientific considerations may have to be adjusted as the exigencies of specific managerial, technical and funding considerations change.

4. Conclusion

Our plan is the 1983 NSAC Long Range Plan, for which we reaffirm our support. The first priority for major construction is to provide first-rate facilities for electromagnetic physics in the few-GeV range. We urge the DOE to continue to do its utmost towards a timely construction of CEBAF. In particular, NSAC is concerned about the delay which has already occurred in this project and about the management problems not yet resolved. The next project, identified in the 1983 NSAC Long Range Plan, is a relativistic heavy-ion collider. The process of studying the designs, choosing the parameters and assessing proposals should start as soon as possible. We hope that construction of the 4-GeV CW electron machine and of the heavy-ion collider will be well under way by the late 1980's. Meanwhile we should discuss strategies for the high-energy hadron physics necessary for a balanced program of nuclear research into the 21'st century and make appropriate recommendations for the continued strength of the base program with the best existing facilities.

Nuclear science faces challenges of unprecedented scope and potential scientific impact. We have an opportunity to study the nuclear response to external probes over an enormous dynamic range. At low energy-momentum transfer, the nuclear response can be described to accuracies of a few percent in terms of nucleon degrees of freedom. At higher energy-momentum transfer, we enter the hadronic regime of excited nucleons and transient mesons. At still higher energies the QCD interface is reached and we can study the mechanism of confinement in many-quark systems. Finally, at very high energy-momentum transfer, we enter the realm of perturbative QCD. Over this enormous dynamic range, the search will go on for new modes of excitation of the nucleus, for new insights into the charge, matter, and color-densities and currents in nuclei, and for new understanding of the nuclear many-body system and of the fundamental interactions and symmetries of nature.

To carry out this rich and very promising program will require facilities that provide a full range of probes -- weak, electromagnetic, hadronic and heavy-ion -- of high intensity, over a wide energy range. This many-facetted, balanced assault on the dynamics of many-hadron systems is the vision of the future that has animated long-range plans for nuclear science from the Friedlander report of 1976 to the 1983 NSAC Long Range Plan. We believe firmly in this vision and in the unprecedented scientific opportunities that it offers.

Mr. FUQUA. All right. I think we will go ahead if Dr. Tigner is present now. Then we will have questions for the two of you.

Dr. Tigner is director of Universities Research Association, a Superconductor Super Collider Central Design Group at Lawrence Berkeley Lab.

Dr. Tigner, we are very glad to have you here again.

[The biographical sketch of Dr. Tigner follows:]

BIOGRAPHICAL SKETCH OF DR. MAURY TIGNER

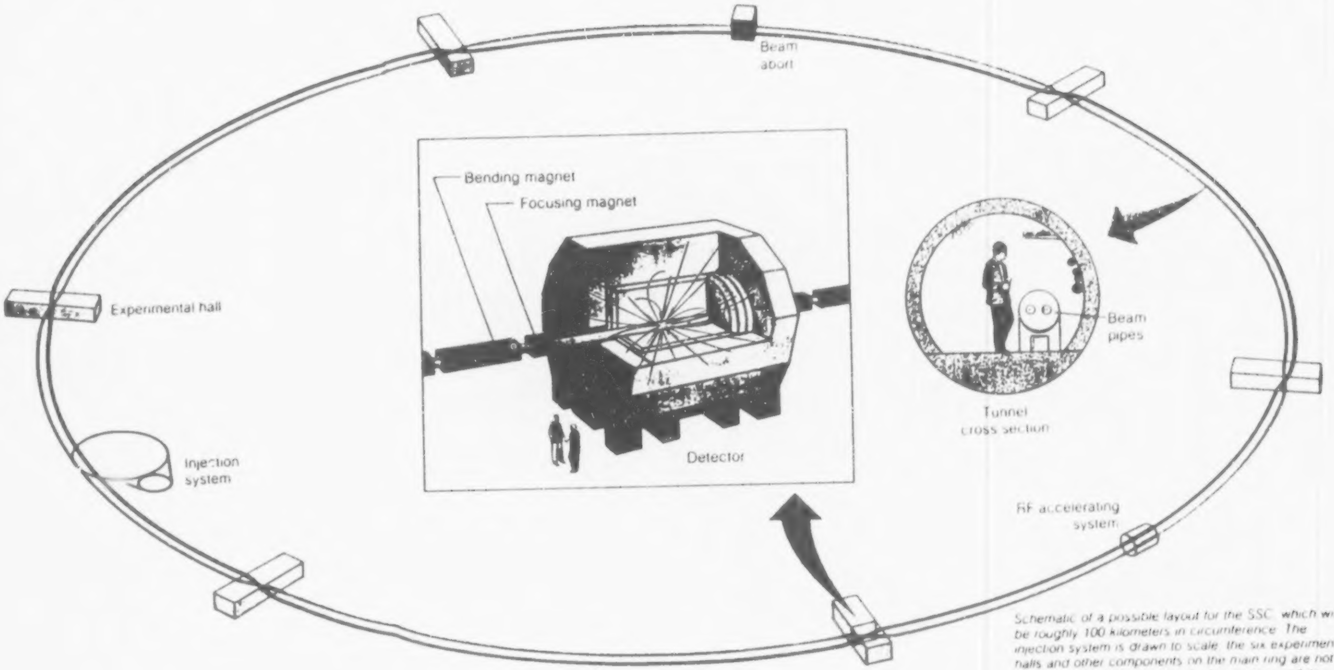
Maury Tigner received his undergraduate education from Webb Institute of Naval Architecture and Rensselaer Polytechnic Institute and received the PhD in experimental physics and electrical engineering from Cornell University in 1962. Since 1958 he has been involved in design, construction and use of accelerators for particle physics at various U.S. and foreign institutions, principally at Cornell. On leave from a professorship in physics at Cornell, he is currently employed by Universities Research Association as Director of the Central Design Group. The Central Design Group is a nationally constituted team of experts drawn together for the purpose of planning the Super Collider.

STATEMENT OF DR. MAURY TIGNER, DIRECTOR, UNIVERSITIES RESEARCH ASSOCIATION, SUPERCONDUCTING SUPER COLLIDER CENTRAL DESIGN GROUP, LAWRENCE BERKELEY LABORATORY, BERKELEY, CA

Dr. TIGNER. Thank you, sir. Mr. Chairman, and members of the subcommittee, thank you very much for this opportunity to appear before you today and give an account of the Supercollider Research and Development Program. This is a nationwide DOE-funded effort.

As you heard in the fall of 1983 and in these hearings 1 year ago, the U.S. high-energy physics community, through the HEPAP, the DOE's advisory panel on high-energy physics, gave its highest priority to the SSC. The scientific need for a multi-TeV collider at the earliest possible time was described by HEPAP Chairman Jack Sandweiss and Dr. Wojcicki, Chairman of the 1983 HEPAP Subpanel on New Facilities.

May I have the first Vu-Graph, please.


Beam abort
Bending magnet
Focusing magnet
Experimental hall
Detector
Injection system
Beam pipes
Tunnel cross section
RF accelerating system

Schematic of a possible layout for the SSC, which will be roughly 100 kilometers in circumference. The injection system is drawn to scale; the six experimental halls and other components on the main ring are not. In the detail of the detector, the beam pipe and its magnets are shown oversize for clarity.

Fig. 1

Conceptually, the SSC consists of two rings of superconducting magnets in which counterrotating beams of protons would each be accelerated to 20 trillion electron volts of energy and made to collide at specified interaction regions, as you can see in the figure.

The energy carried by protons in each beam would be some 20 times that available from Fermilab's Tevatron, the world's first accelerator operating with superconducting magnets. The SSC ring size would necessarily be roughly 20 times that of the Tevatron.

Preconstruction activities in construction of this instrument are expected to take approximately 10 years. The preconstruction phase, phase I, of 3 to 4 years, is to be devoted to advanced accelerator research and development, and engineering studies aimed at establishing a cost-optimized design and construction plan for the facility.

Since 1978, considerable attention has been given worldwide through open scientific meetings to the basic idea embodied in the SSC. In the United States a major study sponsored by the American Physical Society in the summer of 1982, and technical workshops in early 1983, confirmed the feasibility of the SSC, assessed the costs, and also examined the problem of experimentation with such a super collider.

The successful operation of the Tevatron at Fermilab, the first large accelerator utilizing superconducting magnets, provided a validation of the basic systems concepts needed for the SSC. The rich research opportunities expected from the Tevatron collider must be exploited to the full in the coming decade, but it is necessary and prudent to proceed vigorously now with the next step in order to have forefront facilities in the mid-1990's and beyond into the next century.

In response to this need, the DOE supported the SSC Reference Design Study, a 4-month activity, in the spring of 1984 that involved upward of 150 scientists and engineers from laboratories, universities, and industry across the country. The purpose of that study was to examine various options of magnet and systems design, to make technical feasibility studies of the options, and to make the first cost estimates.

The team submitted its report to the Department of Energy in May 1984. In brief, its conclusions were that the SSC is technically feasible and can be based on engineering developments of existing technology. The construction of the accelerator facility, including all conventional infrastructure, but not site acquisition costs or equipment for experiments, was estimated to cost about $3 billion in 1984 dollars, including a large contingency. Extensive DOE review of the Reference Design Study confirmed these conclusions. If one includes all R&D, preoperation costs, and an estimate of the initial complement of detectors and computers, the total rises to approximately $4 billion in 1984 dollars.

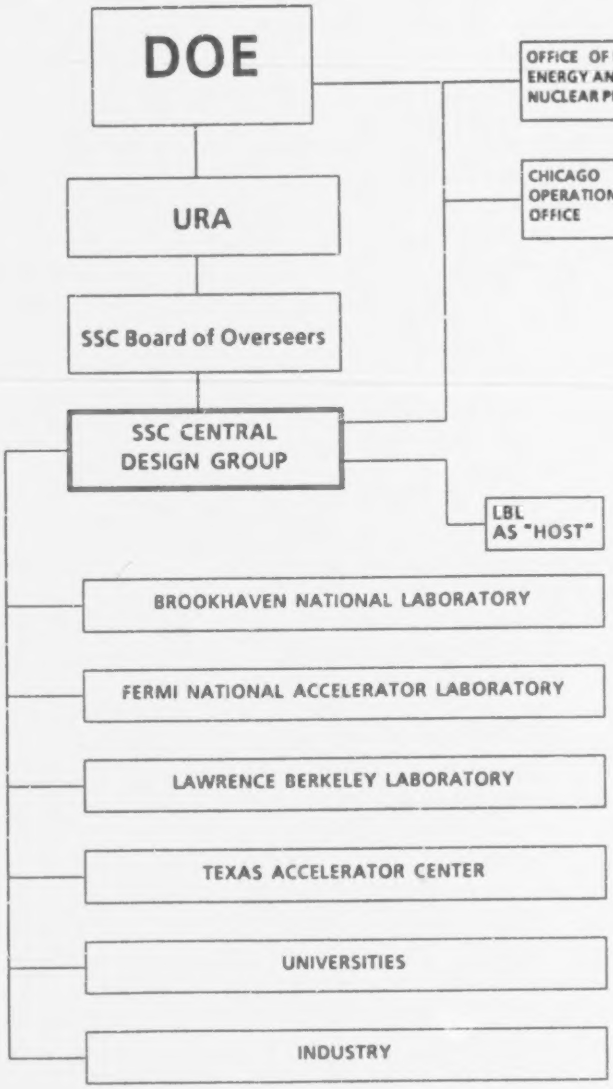

DOE
OFFICE OF HIGH ENERGY AND NUCLEAR PHYSICS
CHICAGO OPERATIONS OFFICE
URA
SSC Board of Overseers
SSC CENTRAL DESIGN GROUP
LBL AS "HOST"
BROOKHAVEN NATIONAL LABORATORY
FERMI NATIONAL ACCELERATOR LABORATORY
LAWRENCE BERKELEY LABORATORY
TEXAS ACCELERATOR CENTER
UNIVERSITIES
INDUSTRY

FIGURE 2

In the spring the Department of Energy designated the Universities Research Association, a consortium of 56 universities in the United States, one of them in Canada, as the contractor for phase I of the SSC project. Phase I refers to the research, development, and design activities prior to construction.

URA established the SSC Design Center on the premises of the Lawrence Berkeley Laboratory, and on October 1 of last year the Central Design Group officially began its phase I activities. The Central Design Group is the nerve center for the supervision and coordination of nationwide research and development efforts carried out at DOE laboratories, universities, and in industry.

May I have the next Vu-Graph, please.

Table 1.

SSC Phase I Program Milestones

Oct 1984		Define Selection Criteria and Technical Information needed for Magnet Selection
Nov 1984		Establish Primary SSC Design Features and SSC Phase I Program Plan Objectives
Apr 1985	*	Site Parameters Document
Apr 1985		Review Magnet Development Program
Jul 1985†	*	Magnet Design Type Selection
Dec 1985		Preliminary Conceptual Design
Feb 1986		Start Pre-Production Prototype Magnets
Mar 1986	*	Conceptual Design Report and Other Documentation
Oct 1986		Magnet Systems Test Begins
Dec 1986	*	Site Selection by DOE
Jun 1987		Report on Systems Tests
Aug 1987		Recommended SSC Phase II Management and Procurement Plans Partial Title I Design Report
Oct 1987	*	SSC Construction Start (NTP)

*Denotes Primary Milestone
†Selection to be made during last quarter of FY85

The objectives of phase I are to accomplish the necessary research and development to, one, delimit all machine and conventional systems parameters to optimize performance and to minimize the cost; two, specify in detail the requirements of the site; to prepare a complete and detailed plan of the envisioned SSC facility, including a firm cost estimate and construction schedule and other important elements.

The time scale of these activities can be gauged by the milestones shown in the Vu-Graph. The major milestones of phase I are the submission to DOE by April 15 of the site criteria document, the selection of the basic magnet type in the latter part of fiscal year 1985, and the completion of the detailed proposal by March 1986, and the hoped-for DOE site selection by the end of 1986.

As evaluation of potential sites is likely to be a lengthy process, we hope that the DOE will proceed vigorously in this matter at an early date.

The largest single activity in fiscal year 1985 is the R&D effort on magnets. Through modeling and engineering analyses, five basic types are being studied by teams at Brookhaven, Fermi, LBL, and Texas Accelerator Center, and cooperating industries.

The information needed to make an intelligent choice of magnet type will flow from the current R&D and cost estimating efforts.

A myriad of other issues are being addressed in fiscal year 1985 with a number of specialized workshops and task forces. Led by the central design group, these draw on the expertise of physicists and engineers from the universities, national laboratories, and industry, as well as from high-energy physics establishments abroad.

In terms of our objectives for 1986, broadly stated, our major effort in fiscal year 1986 will be directed at providing the DOE with the technical and cost information it needs to decide on whether and how to proceed with the Super Collider. The foundation of this was provided by the Reference Designs Study of 1984 and by phase I R&D work currently in fiscal year 1985.

Major items of work will be development of final prototype of the selected basic magnet type, preparation for extensive system tests of the prototype magnets, continued development of improved commercially available superconducting materials, and developments of an optimized technical system design and cost estimate, among others.

With regard to magnets, as already described, an extensive examination of a range of basic magnet types is currently being carried out, with a selection to be made in the last quarter of this fiscal year. Building on the extensive preselection designwork that is being carried out, the final prototype design will be completed in early fiscal year 1986 and prototype construction will begin at a modest budget-limited rate.

In the area of system tests, while the prototype magnets will, of course, be individually tested as they are made, an assessment of their behavior as part of a complete system is crucial in evaluating their effectiveness and reliability as parts of the SSC. Preparations for and a modest beginning of some system tests can be carried out under the proposed budget.

With regard to superconductor development, very important will be the continuation of our drive in collaboration with U.S. industry to improve the electrical current-carrying capacity and characteristics of commercially available material.

Prior to the beginning of the recent improvement program, wire capable of transporting 1,800 amperes per square millimeter of cross section was commercially available. The reference design study assumed in its cost estimates that an improvement to 2,400 amperes per square millimeter would be effected by R&D prior to SSC construction, thereby lessening the amount of superconductor needed and effecting a significant cost saving.

I am extremely happy to be able to report that this goal has already been exceeded, and even higher values may be available for the SSC and for commercial applications.

With regard to designs and cost estimating, based on the accelerator physics and engineering studies which were part of the reference design, and magnet type selection studies of 1984 and 1985, we will be prepared to carry out design optimization and to make cost estimates for complete SSC technical systems based on optimized designs.

Now let me close by discussing the impact of the proposed fiscal year 1986 budget. While the proposed budget will permit substantial accomplishments to be made in evaluation of supercollider technology and cost estimates, progress will be budget limited. Idea and manpower resources are available to support a more robust program of superconductor magnet prototype production and tests. Were budgets available in fiscal year 1986, we could begin a substantial program of industrial involvement in the magnet design and prototyping. This would benefit both SSC and industry by bringing industrial experience and low-cost manufacturing to the scientific community and bringing new technological ideas to the industrial community. The result would be a significant number of magnets to test in a system setting with its concomitant benefit to progress of the SSC Program and heightened industrial experience in the new technology.

In the area of improving commercially available superconducting materials, which would benefit both the SSC and commercialization of the technology, greater funding would permit us to move forward more rapidly. Investigation of both different materials and production methods could be expanded.

Currently, American-made superconducting material is just one step ahead of Japanese and European material in its quality and performance. In fact, part of our R&D program will be to employ certain advanced production equipment that is available only in Europe and Japan in combination with our R&D-generated metallurgical findings to make the next significant step forward in material quality.

More resources available for this work would make such equipment available in the United States as well. The currently proposed funding will permit a significant address to crucial preproposal SSC activities. But opportunities for immediate interplay between basic research and industry are being missed.

Thanks to the support we have received, the technical and cost definitions for the SSC are proceeding well, and the physics needs for this instrument have been firmly established. R&D accomplishments to date have been satisfying both from the scientific point of view and in demonstrating the mutual benefits of basic science-industry interaction. We believe we are ready to move ahead at an increasing pace as national priorities permit.

Thank you.

[The prepared statement of Dr. Tigner follows:]

RESEARCH AND DEVELOPMENT FOR THE SUPERCOLLIDER

M. Tigner

Universities Research Association

Testimony before

Subcommittee on Energy Development and Applications
Committee on Science and Technology
United States House of Representatives

February 28, 1985

Chairman Fuqua and members of the Subcommittee, thank you for this opportunity to appear before you today and give an account of the Supercollider research and development program. This is a nationwide, coordinated, DOE-funded effort on the Supercollider. As you heard in the fall of 1983 and in these hearings one year ago, the U.S. high energy physics community, through HEPAP, the DOE's advisory panel on high energy physics, gave its highest priority to the SSC. The scientific need for a multi-TeV collider at the earliest possible time was described by HEPAP Chairman J. Sandweiss and Dr. S. Wojcicki, Chairman of the 1983 HEPAP Subpanel on New Facilities. HEPAP has recently reemphasized that the Supercollider is essential to the continuing health of the U.S. high energy physics effort and the restoration of U.S. prominence in this frontier field of research. The objectives of particle physics are described in an addendum.

Conceptually, the SSC consists of two rings of superconducting magnets in which counter-rotating beams of protons would each be accelerated to 20 trillion electron volts of energy and made to collide at specified interaction regions. The energy carried by protons in each beam would be some 20 times that available from Fermilab's Tevatron, the world's first accelerator operating with superconducting magnets. The SSC ring size would necessarily be roughly 20 times larger (Fig. 1). Preconstruction activities and construction of this instrument are expected to take approximately 10 years. The preconstruction phase (Phase I) of three to four years is to be devoted to advanced accelerator research and development and engineering studies aimed at establishing a cost-optimized design and construction plan for the facility. A construction period (Phase II) of approximately six years will be necessary for completion.

I. BACKGROUND

In order to place the current R & D efforts and the plans for FY 1986 in context, it is useful to summarize the origins and history of the project. Since 1978, considerable attention has been given worldwide through open scientific meetings to the basic idea embodied in the SSC. In the U.S., a major study, sponsored by the Division of Particles and Fields of the American Physical Society in the summer of 1982, brought forth the realizations that the next needed step in energy was to a multi-TeV accelerator-collider and that such an instrument was practicable. Technical workshops in early 1983 confirmed the feasibility of the SSC, assessed the cost, and also examined the problems of experimentation with such a supercollider. In the summer of 1983, as a result of the deliberations of its Subpanel on Future Facilities, HEPAP recommended unanimously to the Department of Energy the immediate implementation of an effort aimed at construction and operation of a multi-TeV proton-proton collider at the earliest possible date. At about this time, the commissioning of the Tevatron at Fermilab was underway. The successful operation of this pioneering facility, the first large accelerator utilizing superconducting magnets, provided a validation of the basic systems concepts needed for the SSC. As you will hear from Dr. Lederman, the Tevatron is presently a working instrument that soon will have the enhanced capability of collisions between proton and antiproton beams, each with an energy of close to 1 TeV. The rich research opportunities expected from the Tevatron collider must be exploited to the full in the coming decade, but it is necessary and prudent to proceed vigorously now with the next step in order to have forefront facilities for the mid-1990's and beyond.

In response to this obvious need, the DOE supported the SSC Reference Designs Study, a four-month activity in the spring of 1984 that involved upwards of 150 scientists and engineers from laboratories, universities, and industry across the country. The purpose of the Study was to examine various options of magnet and systems design, to make technical feasibility studies of the options, and to make first cost estimates. The team submitted its report to the Department of Energy in May 1984. In brief, its conclusions were that the SSC is technically feasible and can be based on engineering developments of existing technology. The construction of the accelerator facility, including all conventional infrastructure, but not site acquisition costs or equipment for experiments, was estimated to cost about 3 billion dollars (1984 dollars, including contingency). Extensive DOE review of the Reference Designs Study confirmed these conclusions. If one includes all R&D, preoperations costs, and an estimate of the initial complement of detectors and computers, the total rises to approximately 4 billion 1984 dollars.

Another summer study, sponsored by the Division of Particles and Fields of the American Physical Society and attended by 250 high energy physicists from here and abroad, reviewed the physics needs and concluded that 20 TeV per beam gives an adequate energy margin to address confidently the expected questions. It also examined technical issues concerning detectors at the SSC.

Also in the spring of 1984, the Department of Energy designated the Universities Research Association (URA), a consortium of 54 research universities in the U.S. (1 in Canada), as the contractor for Phase I of the SSC Project. As indicated, Phase I refers to the research, development, and design activities prior to construction. Upon recommendation of its SSC Board of Overseers, the URA appointed me Director of the SSC Central Design Group (CDG) to carry out the Phase I activities. URA established the SSC Design Center on the premises of the Lawrence Berkeley Laboratory and on October 1 the Central Design Group officially began its Phase I activities. As can be seen from Fig. 2, the Central Design Group is the nerve center for the supervision and coordination of nation-wide research and development efforts carried out at DOE laboratories, universities, and industry. The CDG itself presently has a staff of 30, mostly physicists and engineers, conducting R&D on specific issues, as well as directing the overall national effort.

II. PHASE I OBJECTIVES

The objectives of Phase I are to accomplish the necessary research and development to

(1) delimit all the machine and conventional systems parameters to optimize the performance and minimize the cost;

(2) specify in detail the requirements of a site;

(3) prepare a complete and detailed plan of the envisioned SSC facility, including a firm cost estimate and construction schedule;

(4) proceed with prototype magnets and other components;

(5) conduct extensive systems tests of the prototype magnets and associated cryogenic and control systems.

The time scale of these activities can be gauged from the milestones shown in Table 1. The major milestones of Phase I are the submission to DOE by April 15 of the Site Criteria Document, the selection of the basic magnet type in the latter part of FY 1985, the completion of the detailed proposal by March 1986, and the hoped-for DOE site selection by the end of 1986.

III. FY 1985 ACTIVITIES

The objectives for FY 1985 are focussed on the preparation of the Site Criteria Document and the accomplishment of the R & D needed to make a selection of the magnet design type.

The Central Design Group has the assistance of an interim architecture and engineering (A/E) firm for the preparation of the Site Criteria Document which will be for DOE's use in establishing site selection criteria. It will spell out in sufficient detail the various physical (geological and geographical), utilities, transportation, and social/human requirements and will contain a recommended list of specific questions to be answered by site proponents. The DOE has already specified the general procedures to be followed in selection of a site. It involves the appointment by the National Academies of Science and of Engineering of a committee of experts to screen qualified site offerings that may be made. This committee will forward a short list of the very best sites to the DOE. The first step is the creation of the Site Criteria Document. That process is on schedule. As evaluation of potential sites is likely to be a lengthy process, we hope that the DOE will proceed vigorously in this matter at an early date.

The largest single activity in FY 1985 is the R & D effort on magnets. Through modeling and engineering analysis, five basic types are being studied by teams at Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley Laboratory, Texas Accelerator Center, and cooperating industries. If I may oversimplify for the sake of brevity, the types differ on the one hand with respect to domination by superconductor or iron in concentrating the magnetic field, and on the other hand with respect to numbers of magnets (and beam pipes) per cryostat, the vessel that contains the liquid helium needed to maintain the ultralow temperature for the creation of superconductivity. Each variant has its virtues. The information needed to make an intelligent choice of magnet type will flow from current R & D and cost estimating efforts.

An important aspect of the accelerator is the so-called aperture, the maximum transverse linear extent of motion of the protons as they circle millions of times around the ring during acceleration and storage. The aperture determines the necessary size of the beam pipe, which determines the amount of superconductor, iron, liquid helium, etc., needed for the magnets and impacts differently on each of the possible magnet types. The smaller the beam pipe, the lower the cost per meter of the magnet system. Millimeters of aperture translate into millions of dollars of cost. Clearly, a prudent choice must be made and considerable effort by accelerator physicists is being devoted to this one aspect. An Aperture Workshop was held last November and an Aperture Task Force continues actively, with April as a target date for a final recommendation.

A myriad of other issues are being addressed in FY 1985 with a number of specialized Workshops and Task Forces. Led by the Central Design Group, these draw on the expertise of physicists and engineers from the universities, national laboratories, and industry, as well as from high energy physics establishments abroad. One example is the recent Workshop on Commissioning and Operation of the SSC, held at LBL in January. Lest you think it rather premature to be discussing commissioning and operation of the accelerator, let me hasten to point out that such considerations have a real and immediate impact on upcoming decisions on magnet type and other components. Experts in the running of the Tevatron in the U.S., the CERN SPS in Europe, and other large accelerators spent a week discussing how one would commission and operate the SSC, coping with the inevitable vagaries of operation of any large and exceedingly complex system. Through the Workshop and subsequent Task Force, criteria are being developed against which to compare the various component designs. The aim is to optimize the workability of the accelerator without compromise on performance or increase in cost.

Other FY 1985 activities include continued interaction with industry to develop still better superconducting materials, and an important experiment being conducted at the synchrotron light facility at Brookhaven on the desorption of gases from the inner wall of the beam pipe by the synchrotron light to be emitted by the multi-TeV protons of the SSC. The latter effort draws on materials science facilities to address an important technical issue for the supercollider.

In the latter part of FY 1985, after the selection of a magnet design type (and so the determination of magnetic field strength and size of the main ring), the Central Design Group will begin a cost-optimized design of the technical and conventional components.

IV. OBJECTIVES FOR FY 1986

Broadly stated, our major effort in FY 1986 will be directed at providing the DOE with the technical and cost information it needs to decide on whether and how to proceed with the Supercollider. The foundation for this was provided by the Reference Design Study of 1984 and by the Phase I R/D work of FY 1985. Major items of work will be:

1) development of final prototype of the selected basic magnet type;
2) preparation for extensive system tests of the prototype magnets;
3) continued development of improved, commercially available superconducting materials;
4) development of an optimized technical system design and cost estimate;
5) creation of a non-site-specific Conventional System Plan and cost range for various possible site types;
6) development of generic environmental impact information.

These items are addressed in more detail below.

Magnets

As already described, an extensive examination of a range of basic magnet types is currently being carried out, with a selection to be made in the last quarter of FY 1985. Building on the extensive preselection design work that is being carried out, the final prototype design will be completed in early FY86 and prototype construction will begin at a modest, budget limited rate.

System Tests

While the prototype magnets will be individually tested as they are made, assessment of their behavior as part of a complete system is crucial in evaluating their effectiveness and reliability as parts of the SSC. Preparations for and a modest beginning of some system tests can be carried out under the proposed budget.

Superconductor

Most important will be continuation of our drive, in collaboration with U.S. industry, to improve the electrical current carrying capacity and other characteristics of commercially available material. Prior to the beginning of the recent improvement program, wire capable of transporting 1800 Amperes per square millimeter of cross section was commercially available. The Reference Designs Study assumed in its cost estimates that an improvement to 2400A/mm^2 could be effected by R/D prior to SSC construction, thereby lessening the amount of superconductor needed and affecting a significant cost saving. I am happy to be able to report that this goal has already been exceeded and even higher values may be available for the SSC and for commercial applications.

Technical Design and Cost Estimate

Based on the accelerator physics and engineering studies which were part of the Reference Designs and Magnet Type Selection Studies of 1984 and 1985, we will be prepared to carry out design optimization and to make cost estimates for complete SSC technical systems based on the optimized design.

Conventional System Plan and Cost Estimate

A cost estimate for conventional systems based on a "median" site was featured in the Reference Designs Study. An important supplement to that will be development of cost ranges to be expected for potential real site variations. In addition we will need to develop further the non-site-specific features of the conventional systems to optimize their adaptation to scientific need. Further studies of utilities distribution and organization of other site services and arrangements will also be needed to assure cost effectiveness of the conceptual design.

Generic Environmental Impact Information

Selection of a suitable site for the SSC will be crucial for maximizing its cost effectiveness. Accordingly it will be important to study extensively the potential impact of the SSC on its environment and the implications of various types of environment for SSC costs. It is expected that this process will continue throughout the period prior to site selection.

V. IMPACT OF THE PROPOSED FY 1986 BUDGET

While the proposed budget will permit substantial accomplishments to be made in evaluation of supercollider technology and cost estimates, progress will be budget limited. Idea and manpower resources are available to support a more robust program of supercollider magnet prototype production and test. Were budget available in FY 1986, we could begin a substantial program of industrial involvement in the magnet design and prototyping. This would benefit both SSC and industry by bringing industrial experience in low cost manufacturing to the scientific community and bringing new technological ideas to the industrial community. The result would be a significant number of magnets to test in a system setting with its concommitant benefit to progress of the SSC program and heightened industrial experience in a new technology.

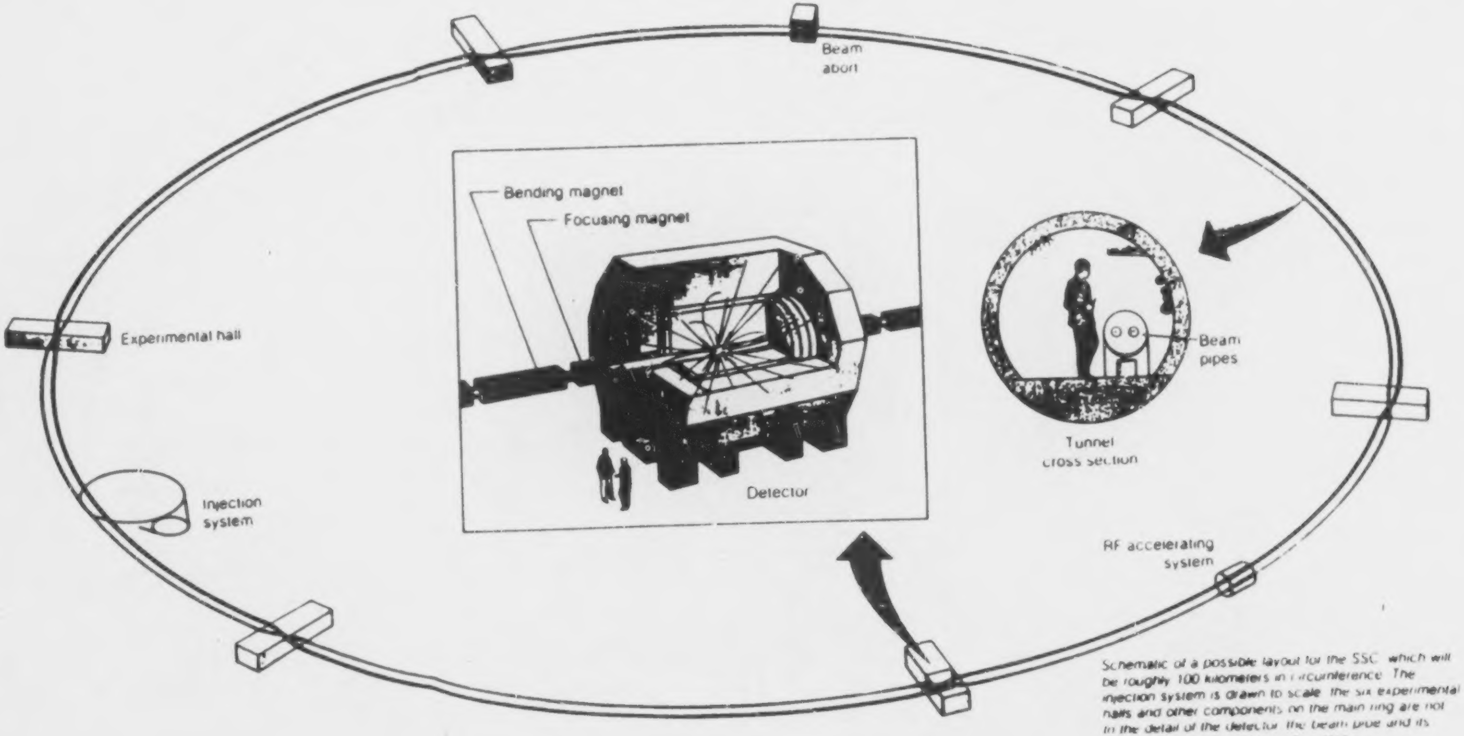
In the area of improving commercially available superconducting materials, which would benefit both the SSC and commercialization of the technology, greater funding would permit us to move forward more rapidly. Investigation of both different materials and production methods should be expanded. Currently American-made superconducting material is just one step ahead of Japanese and European material in its quality and performance. In fact, part of our R/D program will be to employ certain advanced production equipment that is available only in Europe and Japan in combination with our R/D-generated metallurgical findings to make the next significant step forward in material quality.

More resources available for this work would make such equipment available in the U.S. as well. The currently proposed funding will permit a significant address to crucial preproposal SSC activities, but opportunities for immediate basic research-industrial symbiosis are being missed.

VI. CONCLUSION

Thanks to the support we have received the technical and cost definitions for the SSC are proceeding well and the physics needs for this instrument have been firmly established. R/D accomplishments to date have been satisfying both from the scientific point of view and in demonstrating the mutual benefits of basic science-industry interaction. We believe we are ready to move ahead at an increasing pace as national priorities permit.

(0420S)


Beam abort
Experimental hall
Bending magnet
Focusing magnet
Detector
Injection system
Tunnel cross section
Beam pipes
RF accelerating system

Schematic of a possible layout for the SSC, which will be roughly 100 kilometers in circumference. The injection system is drawn to scale; the six experimental halls and other components on the main ring are not; in the detail of the detector the beam pipe and its magnets are shown oversize for clarity.

Fig. 1

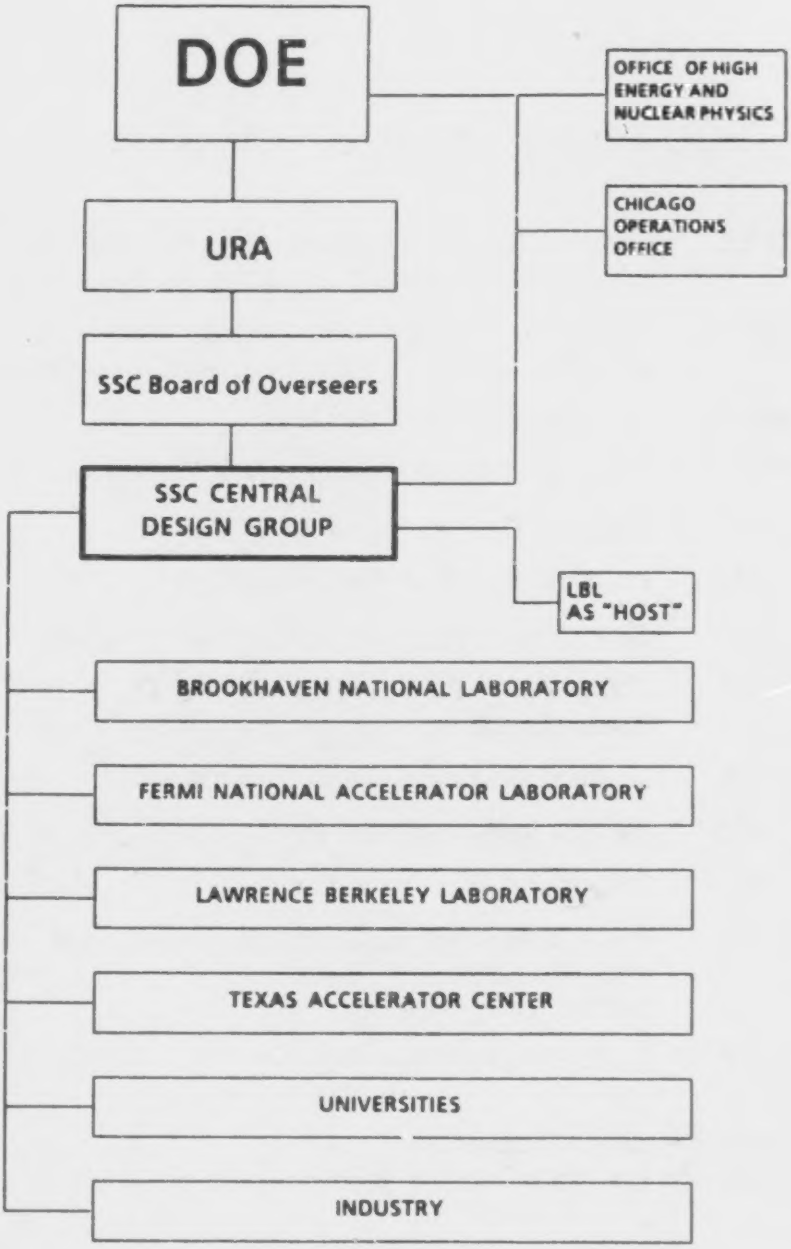

DOE
URA
SSC Board of Overseers
SSC CENTRAL DESIGN GROUP
OFFICE OF HIGH ENERGY AND NUCLEAR PHYSICS
CHICAGO OPERATIONS OFFICE
LBL AS "HOST"
BROOKHAVEN NATIONAL LABORATORY
FERMI NATIONAL ACCELERATOR LABORATORY
LAWRENCE BERKELEY LABORATORY
TEXAS ACCELERATOR CENTER
UNIVERSITIES
INDUSTRY

FIGURE 2

Table 1.

SSC Phase I Program Milestones

Oct 1984		Define Selection Criteria and Technical Information needed for Magnet Selection
Nov 1984		Establish Primary SSC Design Features and SSC Phase I Program Plan Objectives
Apr 1985	*	Site Parameters Document
Apr 1985		Review Magnet Development Program
Jul 1985†	*	Magnet Design Type Selection
Dec 1985		Preliminary Conceptual Design
Feb 1986		Start Pre-Production Prototype Magnets
Mar 1986	*	Conceptual Design Report and Other Documentation
Oct 1986		Magnet Systems Test Begins
Dec 1986	*	Site Selection by DOE
Jun 1987		Report on Systems Tests
Aug 1987		Recommended SSC Phase II Management and Procurement Plans Partial Title I Design Report
Oct 1987	*	SSC Construction Start (NTP)

*Denotes Primary Milestone

†Selection to be made during last quarter of FY85

Addendum

WHAT IS HIGH ENERGY PHYSICS AND WHY THE SSC?

The objective of high energy physics is to identify the ultimate constituents of matter and to understand the basic forces that bind these constituents to form the world we know. Such questions have been viewed as fundamental since the earliest times. In this century they have led physicists to create large accelerators such as those at CERN, Europe's high energy physics laboratory near Geneva, Switzerland, and the facilities at Fermilab, near Chicago.

Just as x-rays, with their higher energy and shorter wavelength, permit the study of molecules and even single atoms in a way that ordinary light does not, so the far more energetic particle beams from today's big accelerators probe to the heart of any target put in their path. Part or all of this immense concentration of energy is converted into the creation of matter; a profusion of particles of varying degrees of stability is produced. Large and ingenious detectors receive and record the pattern of particles, often in time intervals measured in billionths of a second. In addition to experimentation at these large accelerators, the study of fundamental particles and their interactions relies on valuable information from other sources. Studies with cosmic rays, measurements at nuclear reactors, the search in the shielded environment of deep tunnels and mines for rare decays of nuclear particles, and the precise study of atomic transitions have all added to our understanding of elementary particle physics.

Yet many questions can be answered only by probing still deeper into the interior of the proton with increasingly energetic particle collisions. For this reason, a 1983 Department of Energy advisory panel recommended the rapid initiation of a new, extremely high energy accelerator. This proposed device, in which two beams of protons would collide head-on, is called the Superconducting Super Collider (SSC). The parameters of the SSC are dictated partly by the existing facilities at CERN and Fermilab, with their capabilities for studying collisions at total energies approaching or exceeding one trillion electron volts, and partly by the expectations of new, perhaps revolutionary, phenomena requiring beam energies of many TeV and very high fluxes of colliding particles.

The technology needed for such a project has now come of age. After more than 20 years of superconducting magnet research and development in the United States, a large superconducting accelerator, the Fermilab Tevatron, has been constructed and is operating successfully. The basic phenomenon of superconductivity has been known since 1911; but a complete theoretical understanding was achieved only in 1957. By now, the interplay of scientific endeavors and the metals industry has produced a technology capable of manufacture of sufficient quantities of sophisticated conductor materials with uniform enough quality for extensive applications. As a result, superconducting magnets are routinely used in large detector magnets and beam-transport lines. However, the Fermilab Tevatron is the first full-scale high-energy accelerator using superconducting magnets, marking a pioneering step in accelerator physics and technology. Full exploitation of this technology, leading to an increase in energy by more than a factor of ten over the Tevatron, appears feasible at the present time.

It is the nature of the field that investigations at one high-energy facility provide answers to some questions, yet raise new questions that can be answered only at a different, generally more powerful facility. From the early synchrocyclotrons to the Cosmotron at Brookhaven, the Bevatron at Lawrence Berkeley Laboratory, the AGS at Brookhaven, the ZGS at Argonne, the electron linac at SLAC, the Fermilab 400 GeV and now 1 TeV accelerator, and the electron-positron colliders at SLAC and Cornell, to mention only US machines, proton and electron accelerators and colliders have addressed important questions and provided significant and often startling answers over the years. Progress in the field is paced chiefly by the rate of discovery at these facilities.

The past twenty years have seen remarkable accomplishments — the discovery of point-like constituents inside the proton (SLAC), the psi family of particles indicating a new heavy quark (BNL, SLAC), the upsilon family (Fermilab, Cornell), neutral weak currents (CERN), evidence for the gluon (DESY), to name only a few. The most recent, truly impressive discoveries are of the massive weak vector bosons ($W^{\pm}, Z^0$), achieved at CERN in 1982-83. The numerous experimental discoveries and the accompanying (sometimes preceeding) theoretical developments encourage particle physicists to believe they have achieved a partial synthesis, surely incomplete but sufficient to focus with confidence on the next step. Today's unanswered questions point to the TeV energy scale as crucial to further progress. Study of new particles and interactions in this energy regime requires high intensity proton beams with energies of tens of TeV.

Whatever the physics of the TeV energy region turns out to be, its exploration will inject sorely needed guidance into our attempts at a still deeper theoretical description of nature. This exploration is made possible by the more than two decades of research and development we have invested in superconducting magnet technology. The Superconducting Super Collider offers the very real probability of truly major advances in our growing understanding of the patterns of elementary particles and the unification of the forces of nature.

(0421S)

PANEL 3—DISCUSSION

Mr. **Fuqua**. Thank you. Thank you very much.

Dr. Schiffer, in the budget you mentioned—you didn't give the figures—but the underutilization of our national physics accelerator facilities scheduled to drop from about 55 percent to about 45 percent under the current budget. When we're only utilizing 45 percent of our capacity, how do we justify new facilities?

Dr. **Schiffer**. That is a difficult question. Many of these facilities are unique in some areas. If you take the most important projects which they address and don't do the next most important and next most important, they are utilized some fraction of the time. The question is, Do we want to address the most important scientific questions or is it a matter of being content to have a group of out-of-date facilities that we keep utilizing inadequately? Some compromises will have to be made in time, and I do not mean to imply that every single accelerator that exists now should continue in existence indefinitely.

Mr. **Fuqua**. Well, if the current funding levels continue, what sort of choices are left to the nuclear physics community to make if we're operating too many facilities at under capacity?

Dr. **Schiffer**. It is very difficult to address the question without a specific budget. If somebody gave our committee a statement, "This is the budget for the next 5 years, how would you"——

Mr. **Fuqua**. But you had a chart that showed how the funding had dropped down since the early 1970's, I think.

Dr. **Schiffer**. In the long-range plan we made——

Mr. **Fuqua**. If that continues, even at a rather level figure.

Dr. **Schiffer**. If it continues without money for new construction, I don't know that we can undertake the items that we had. We would try to do something with existing facilities and try to do the best we can. But we have to plan for what we think is reasonable and what we think is important.

Mr. **Fuqua**. Right.

Dr. **Schiffer**. If we just forget about planning for the future, then we might as well plan to fade out.

Mr. **Fuqua**. Close up shop?

Dr. **Schiffer**. Yes.

Mr. **Fuqua**. Dr. Tigner, in your chart on the SSC, you had—it apparently was made some time ago—about the timetables for the SSC. How much will that phase I slip based on the $20 million that's in the budget this year?

Dr. **Tigner**. Well, that, of course, is a difficult question to answer. If we assume that other things remain equal and the commitment by the DOE is made at pace, which we would hope that they would be willing to make, then I would guess that to date this would imply a slippage of something like 6 months in the overall completion of the project.

Mr. **Fuqua**. Only about 6 months?

Dr. **Tigner**. If we can recover from it. If this means that the——

Mr. **Fuqua**. If they give?

Dr. **Tigner**. Yes.

Mr. **Fuqua**. But it looks to me like it will slip probably even a year or more, based on——

Dr. TIGNER. It could easily do that, sir.

Mr. FUQUA. And what will that do to the cost?

Dr. TIGNER. It's certainly going to mean that the cost will rise. There is no getting around that. It's a law of nature. Exactly what the quantity in the cost will be, of course, depends upon economic factors and the efficiency with which we're able to use facilities. It certainly is going to be the cost of inflation, and it's likely to be somewhat worse than that.

Mr. FUQUA. What involvement have you made of the international physics community in the phase I and their participation possibly in the overall project?

Dr. TIGNER. Thank you. That's a very good question. Of course, the broader question of involvement at the intergovernmental level has to be left to others. However, as you know, the particle physics community have been for many years very internationally-minded and have been rather effective in arranging what you might call grassroots collaborations. We trade scientific equipment back and forth all the time. We go there to do experiments; they come here to do experiments.

We have multinational groups arranged without the help—or hinderance, maybe—of governmental bodies. And likewise with the SSC, we certainly anticipate a strong international usage, and we have already begun to incorporate, and have incorporated, individuals from various institutions abroad both from Japan and Europe in various of our group activities at the design center.

Mr. FUQUA. Well, would that involve participating in the capital costs, or that's just in operations?

Dr. TIGNER. The approach that I have been taking, since it's not my prerogative to deal with governments about capital costs, is to try to get the individuals who are involved excited about it and hope that that other deeper participation will follow.

Mr. FUQUA. Mr. Mineta.

Mr. MINETA. Mr. Chairman, let me just ask one.

Because of the size of this, Dr. Tigner, I was wondering is this one of those where we really ought to be talking about international collaboration? I mean we're talking about what, $4 or $5 billion?

Mr. FUQUA. I would say more than that.

Mr. MINETA. More than that?

Mr. FUQUA. By the time it gets finished, where they're estimating in 1984 dollars at $3 to $4 billion.

Dr. TIGNER. $3 billion is the estimated, carefully estimated, cost of constructing the accelerator itself, including contingency, with another billion to outfit it and do the R&D and get it ready for operation.

Mr. FUQUA. And that's in 1984 dollars. If it goes to start in 1987, even if you follow that, or if it's even in the year 1988, and you add construction cost increases and so forth, I think, you're talking at least $6 billion-plus.

Mr. MINETA. And it seems to me that given the earlier question I had asked about utilization of existing facilities dropping, and here we're squeezing existing labs in terms of the amounts of moneys that are available to them, then now we're looking at something like this as a new facility with these tremendous costs, it just seems to me that it just makes it that much tougher to try to plead a case like this, especially when high-energy physics hasn't gotten the kind of support that I guess a lot of us have been looking to in order to say, "Yes, we really ought to go ahead with something like this."

Dr. **Tigner**. Well, you're certainly right. It's a very important question. You'll find, I think, that the U.S. particle physics community is quite receptive to any kinds of ideas about international collaboration. I can tell you that foreign industries are very interested in international collaboration. They sure would like to get involved in this technology. We've already got lots of people coming around and saying, "How can we get in the act?"

Mr. **Mineta**. Thank you, Mr. Chairman.

Mr. **Fuqua**. Mr. Barton.

Mr. **Barton**. Mr. Chairman, I have several questions. I am a new member of this subcommittee, so I am a real novice. I have a very basic question.

The question is, What do we gain if we build the SSC? What do we gain over what we actually have today?

Dr. **Tigner**. Particle physics addresses the most basic questions about the structure of matter: Are there truly elementary bits of matter; what are the rules by which they're put together to form the world around us; what are the forces that play to govern the behavior of microscopic matter; is there only one force really, or are there lots of different forces?

It is the answers to this type of questions that form the very foundation upon which we build the technology that we are living on today.

Mr. **Barton**. But let's assume that you and your fellow scientists can determine those answers and we know the answer. If we can find the answer, does that give us the ability to come up with a better energy source in nuclear fusion? I mean, in a practical sense, what good does the knowledge do us if we know what the very basic building blocks of matter are?

Dr. **Tigner**. Well, of course, since we're talking about something that's to happen in the future, we can't predict it with certainty. All we have, of course, is history as a guide. We know that this particular quest, the quest for the understanding of the basic nature of matter, has led us to the technology we have today. Something like 80 or 90 years ago, the electron was discovered as the result of a completely academic study which had absolutely no relevance to any practical thing at all. Today our entire electrical and electronics industry, to say nothing of materials industries, are based upon the discoveries that were made at the turn of the century. And so it has gone.

The discovery of the fundamental nature of matter has preceded its turning into basic technology by anywhere from 40 to 80 years. Can I predict some particular energy source based upon what we're doing? The answer is, "Absolutely no."

Mr. **Barton**. Well, let me ask a few more mundane questions, and you can educate me without the rest of the audience being around. On your site criteria document, who is in charge of preparing that document and going through the site selection procedure?

Dr. **Tigner**. The Department of Energy will be the controlling body in the site selection. The Central Design Group, to which I just referred, is acting as a technical adviser to the Department of Energy, and we will recommend to them a site criteria document which will describe the technical requirements for the accelerator, the utilities that are needed and so forth. They will take that and then make it part of their own criteria, perhaps modified.

Mr. BARTON. And the actual criteria will actually be completed this year, is that correct?

Dr. TIGNER. We will submit our advice to the DOE on April 15, 1985.

Mr. BARTON. OK. And then if DOE approves that, then you'll actually begin to go out and look at possible sites, is that correct?

Dr. TIGNER. Well, sir, the Department of Energy will maintain the prerogative of actually issuing any invitations. And you should urge them on in that important activity. [Laughter.]

Mr. BARTON. OK. Let me ask another question——

Dr. TIGNER. And by the way, any time you want to come and hear all about particle physics, we'd be absolutely delighted to speak with you.

Mr. BARTON. Well, I need to learn about it. I need to learn a lot on this committee.

You mentioned in your prepared testimony five different types of magnets. Now, it's my understanding that you're actually building a working model of some of those magnets this year. Is that what the $20 million is for?

Dr. TIGNER. Yes, sir.

Mr. BARTON. OK. And very briefly, in your prepared testimony you say basically that there are pros and cons, or you say, "Each variant has its virtues." Would you mind very briefly running through the virtues of the various types, for my benefit?

Dr. TIGNER. Certainly. While we're studying five variants, there are two really principal types of magnets that are under consideration. One, in which the magnetic field is produced almost entirely by currents flowing in wires which are arranged in a precise pattern to make the magnetic field be uniform, that we might call the high-field type of magnet.

On the other end of the spectrum there is a lower-field type of magnet on which the magnetic field is shaped by iron pole pieces, although there are superconducting materials still carrying currents which are the basic sources of the magnetic field. So it's now an engineering question whether the somewhat higher cost of the high-field magnets but smaller size of the overall facility balances out economically against the somewhat lower cost per unit length of the iron magnets but the much larger size of the civil works that go into it.

Mr. BARTON. What is the order of magnitude cost differential? Are we talking about 40 percent or 200 percent or 10 percent between the two extremes in the cost?

Dr. TIGNER. The cost per unit of length, if you will, of these devices, one of which does twice as much bending as the other, is something like a factor of two.

Mr. BARTON. Factor of two.

Dr. TIGNER. But we're worried about the overall cost of the entire facility, so we have to keep our eye on the ball, so to speak.

Mr. BARTON. That's all the questions I have, Mr. Chairman.

Mr. Fuqua. Mr. Fawell.

Mr. Fawell. No, I have no questions, Mr. Chairman.

Mr. Fuqua. Thank you.

Mr. Carney, did you have a quick question?

Mr. Carney. Just one.

Mr. Fuqua. Mr. Carney is a former member of our committee. We somehow let him come back every now and then. [Laughter.]

On subjects that are of interest to him.

Mr. Carney. Mr. Chairman, by listening to how this committee hearing is progressing, I never realized that I contributed so much to this committee until I left it. [Laughter.]

And I think I did some very good crystal-balling for several years.

What size are we looking at energy-wise for the SSC?

Dr. Tigner. 20 TeV.

Mr. Carney. 20 TeV. That's the only question I have right now. Perhaps I can ask you some questions off the record. I don't want to indulge upon the time of the committee members.

But I would just like to tell Joe Barton, my friend from Texas, that that ratio between size and money that they're talking about, keep in mind the bigger it is the better chance Texas has to get it. [Laughter.]

Mr. Barton. I just want to do what's right for the American taxpayer. [Laughter.]

Mr. Carney. As long as it's in Texas. [Laughter.]

Mr. Fuqua. Thank you both very much. We appreciate your being here this afternoon and this morning.

Dr. Tigner. Thank you.

[Questions and answers for the record follow:]

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439
Telephone 312/972- 4066

March 18, 1985

RECEIVED
[illegible] 1985
COMMITTEE ON SCIENCE
AND TECHNOLOGY

Congressman Donald Fuqua
Chairman, House Committee on
Science & Technology
U.S. House of Representatives
Suite 2321
Rayburn House Office Bldg.
Washington, D.C. 20515

Dear Congressman Fuqua:

I appreciated the opportunity to testify before the Subcommittee on Energy Development and Applications on February 28, 1985 and am very pleased to respond to the additional questions posed by the Subcommittee.

Question 1: "Barring an infusion of construction funds in FY 1986, what enhancement of funding would you recommend to keep the program on an even keel?"

The FY 1986 nuclear physics programs in the Department of Energy need an increase of about 15% in operating funds and about 20% in equipment and accelerator improvement funds in order to reach a modestly sensible level of utilization of facilities, to permit essential major instrumentation projects to proceed, and to carry out the important facility-related R&D activities that are needed for the future of the field. Such an increment would allow the science recommended in the 1983 Long Range Plan for Nuclear Science to proceed at a rational pace and would keep activities on a sensible even keel while remaining consistent with the overall budget stringencies.

I had summarized in my testimony, the severe implications of the FY 1986 budget submission for nuclear science and some of the major current activities.

Question 2: "We sent you a copy of the Committee's Science Policy Task Force's Report, 'An Agenda for a Study of U.S. Energy Policy'. Would you like to comment on the Report?"

The Report formulates a set of crucial questions that establish the framework for this important study. The scope of the proposed study is very broad. It certainly affects nuclear science and many of the questions asked on the justification of basic research, societal impacts, manpower, and establishing a scale against which financial support of basic research may be measured in an advanced high-technology society, are discussed in our Long Range Plan report.

US Department of Energy The University of Chicago

Please let me know how the Nuclear Science Advisory Committee, or I personally, can be of assistance in connection with this critical undertaking. We all await the outcome of your study with considerable interest.

Sincerely yours,

John P. Schiffer
Chairman
DOE/NSF Nuclear Science Advisory Committee

JPS/bw

Superconducting Super Collider
Universities Research Association
c/o Lawrence Berkeley Laboratory, University of California
One Cyclotron Road, Mail Stop 90-4040
Berkeley, California 94720
(415) 486-4772 – FTS 451-4772

RECEIVED
[illegible]
COMMITTEE ON SCIENCE
AND TECHNOLOGY

March 15, 1985

The Honorable Don Fuqua
Chairman
Committee on Science and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Fuqua:

Thank you for your letter of March 5 with its penetrating questions with regard to my testimony before you of February 28. My response is on the enclosed pages.

Again, thanks for the opportunity to appear before the Subcommittee on Energy Development and Applications to describe progress on the Supercollider, an important need for American science in the 1990's.

Sincerely yours,

Maury Tigner

MT:dm
Enclosure

Questions

FY 1986 DOE Authorization for Basic Research

February 28, 1985

1. What level of funding was assumed for Phase I in order to meet the stated objectives in the time scale envisioned?

   Initial planning in early FY 1984 envisioned a three year program of R/D, planning, and preparation for construction. An estimate of 170M$ was made for the completion of all preconstruction R/D and engineering work including conventional systems as well as all technical systems.

2. You note that progress in FY 1986 will be budget limited. Does this mean that the Phase I milestones will slip in time? Alternatively, if we try to maintain the same milestone dates, what will be the major areas of uncertainty?

   If funding is held at 20M$ there will certainly be a delay in the completion of the SSC. How that delay is shared between Phase I and Phase II depends not only on funding but on whether DOE site selection, which is on the critical path, is completed as shown in the milestone chart which I displayed during my testimony.

   Anticipated in our original plan was a robust program of preconstruction research, development and design work directed at all aspects of the SSC from superconducting magnets to conventional construction matters. Since the time of the original plan significant developments have taken place, all of which affect the schedule in various ways. On the positive side, improvements in superconducting materials needed to realize the important cost savings anticipated in the Reference Designs have come faster than expected. In addition, we have devised ways of selecting the basic magnet type on a shorter time scale than originally expected. Both of these effects shorten time scales and reduce costs. On the negative side, the DOE proposed budget for FY 1986 is less than anticipated in our plans. In responding to this circumstance in our planning we have taken advantage of the positive factors mentioned above and attempted to mitigate the influence of the negative factors on the most crucial of the Phase I milestones.

   Our current plan concentrates available resources on R/D items with possible technical and cost risk such as superconducting dipole magnets and delays certain design and development items characterized by less technical risk such as focusing systems, accelerating and beam handling systems, injector systems and conventional systems. As devices and systems very similar to these latter items have been built before and operated reliably over many years they can be accomplished in Phase II, delaying completion of course, but not incurring significant risk.

3. How much will Phase I slip if FY 1986 funding is held at $20 million? Can this slippage be recovered with an infusion of funds in FY 1987, and if so, how large an infusion would be required?

As indicated in my answer to Question 2, our current plan concentrates available resources on R/D items with possible technical and cost risk. Given the 20M$ FY86, the associated milestones will be met. Other tasks which require time and monetary resources will inevitably be delayed. The extent to which the projected project completion could be recovered with substantial FY87 funding is currently under intensive study.

I would like to reiterate that a key milestone in the current Phase I plan is the site selection by DOE. A delay in meeting that milestone will result in direct delay of project completion.

4. What is the current level of industrial involvement in Phase I? What do you anticipate the role of industry to be in the SSC?

Currently, there is a high and successful level of industrial involvement in Phase I activities. First among them is the successful production of continually improving superconducting material and cable which will benefit both SSC and the growing commercial applications. Industrial firms are now also engaged in making magnet models, in helping us select the particular basic magnet type to go forward with and in helping bring their experience in reliability analysis and planning to bear on SSC matters. Also of note in Phase I is the engagement of industrial consultants expert in geotechnical, civil engineering and environmental matters. They are helping with formulation of site criteria, evaluation of various tunneling technologies and in cost estimating matters.

The role of U.S. industry in Phase II of the SSC project will depend on whether the SSC is predominantly a U.S. project or one characterized by heavy international collaboration. In the former case, my advice to the prime contractor to DOE would be that conventional systems be executed almost exclusively by U.S. industry with direction from the contractor. In the area of technical systems, my recommendation would be that all of the materials and components be supplied by industry, as has been the practice for U.S. accelerator projects in the past, and that as many of the sub-assemblies as possible be industry supplied. As the responsibility for technical success and reliability of the SSC will rest with the contractor my

3

advice would be to insist that the contractor be directly responsible for quality assurance and final system assembly and test. In this picture the preponderance of the value of the project would be produced by industrial firms.

In the case of international collaboration, the role of industry may be more complex. It is likely that international collaborators will want to contribute "in kind" and supply a substantial portion of the high technology materials, such as superconductor, and components and sub-assemblies. They may also wish to participate directly in civil construction. Here it will be doubly important, because of the additional organizational complexity, for the contractor to assume a central responsibility for quality assurance, acceptance testing and final system testing.

5. Given the current budget, will you be able to start pre-production prototype magnets in February 1986 and be ready to begin magnet systems test by October 1986? If not, will we really have a handle on the magnet costs?

It will indeed be a challenge to have a good handle on magnet costs by the time projected for Congressional consideration of SSC construction. One of the major uncertainties, namely commercial achievement of superconductor performance posited in the cost estimate of the Reference Designs, has essentially been accomplished. We will, even under projected budget conditions, have a few prototype magnets for beginning system tests at the beginning of FY 1987. Lacking will be prototype mass production experience for assessment of all possible cost savings. Thus the cost estimates available in early Calendar 1987 will need to be conservative as in the Reference Designs Study. Any possible increment to the FY 1986 budget would be used for industrial contracts to mitigate this deficiency. 5M$ would have a significant impact by permitting industrial contracts for prototypes as well as manufacturing plan and cost estimating studies.

6. We sent you a copy of the Committee's Science Policy Task Force's Report, An Agenda for a Study of U.S. Science Policy. Would you like to comment on the Report?

As science and the results of scientific research have become such an important part of our lives, this is a most important study. The proposed agenda is well directed and will explore the central issues. As a consequence it should be possible to secure enthusiastic participation from the diverse communities that have something to contribute to the exploration and clarification of these deep and complex issues. It will be widely appreciated that success in this study will mean a sharpened ability to use science in the service of our broader goals.

MT:dm
3/15/85

PANEL 4—HIGH ENERGY AND NUCLEAR PHYSICS LABORATORY DIRECTORS

Mr. FUQUA. Our fourth panel is the high energy and nuclear physics laboratory directors: Dr. Leon Lederman, the Director of Fermi National Laboratory, and Dr. Burton Richter, Director of the Stanford Linear Accelerator Laboratory, and one that Mr. Carney has an interest in, and I would like to call on him to introduce the Director of the Brookhaven Lab.

Mr. CARNEY. Well, thank you, Mr. Chairman. I am delighted to have the opportunity to introduce Dr. Nicholas Samios to the committee. The chairman, I am sure, and those who served on the committee before are very familiar with Nick and the job he is doing up at Brookhaven National Laboratory. But he is with two laboratory directors who are equally capable and run labs that are almost as good as Brookhaven Lab, and I am delighted to be here in the company of these three great lab directors.

Mr. FUQUA. Thank you.

I want to thank all of you for your indulgence because we have had a long program today, and you have been very kind and patient.

Dr. Lederman, we would be happy to hear from you, and then Dr. Richter and Dr. Samios.

STATEMENT OF DR. LEON M. LEDERMAN, DIRECTOR, FERMI NATIONAL LABORATORY, BATAVIA, IL

Dr. LEDERMAN. Thank you, Mr. Chairman. I would with your permission like to abbreviate my remarks.

Mr. FUQUA. We will make your prepared remarks, all three, part of the record. And if you wish to summarize, we do have another hearing starting in here in 25 minutes supposedly. We were supposed to start at 2 p.m., but moved it back to 2:30.

Dr. LEDERMAN. Let me just comment that I noted with pride the previous testimony which indicated that both in materials science and in nuclear science the number one priority for both groups was to build high-energy accelerators. Those accelerators were pioneered by our community, and my colleagues in this field have many virtues, but one of them is not humility. They believe that this subject will continue to influence other sciences and society in a very profound way.

My report is on the status of Fermilab and its main project, the Tevatron, and like "all Gaul," the Tevatron is divided into three parts. The first is the accelerator. The accelerator was constructed in the period 1979 to 1983. The first successful operation took place in July 1983. In October we started a physics program. Today we are operating routinely for physics research, applying 800-GeV protons to 10 targets and an equal number of university-based research teams. I should stress that this is the highest energy accelerator in the world, although at the highest effective energy must use head-on collisions, and that record is now in Europe.

We constructed this machine to open up new domain of observations. We didn't realize in 1979 that this would be an essential prototype of the future of our field, the SSC. In my testimony last year I told you that this was not an easy machine to build. Superconductivity is still a pretty exotic technology, and our work represents by far the most extensive systems application of this technology and its associated engineering, cryogenic engineering, ever carried out.

Incidentally, we have held several intensive briefings for industrial firms, always with full lecture rooms crowded with representatives of General Electric and Westinghouse and Martin-Marietta, General Motors, and many other great corporations, as well as representatives of Japanese and German industry coming to see what we have accomplished in order to learn more about quarks.

There is a lot to be done on the accelerator this year and next. We've got to raise the energy from 800 billion volts to 1 trillion volts. This is an important part of our goal. We've got to increase the intensity of the beams, and we've got to increase the reliability of all the systems we have. Finally, we will continue to carry out experiments on the accelerator that serve the SSC R&D Program.

The second project we have is the utilization of the Tevatron accelerator in two components. One is called Tevatron II. We're counting backwards. This is a project that permits us to upgrade the beam lines and experimental halls to handle 1,000-GeV protons and to provide the variety of particle probes required for the elucidation of the very subtle quark substructure of matter. I have described this experimental program in a little more detail in the report I submitted.

The Tevatron II project will be completed within its original budget and will provide 14 beam lines—some new, some simply upgraded—to handle the higher energy.

The university users of Fermilab consist of over 600 customers, including almost 200 graduate students from some 70 U.S. institutions, and some scientists from some 20 foreign countries who are involved in our program.

It is the opportunities of the physics program that quicken the pulse and brighten the eye. I must confess, Mr. Chairman, that I occasionally play hookey from the director's office at Fermilab to spend some time with my young friends doing an experiment I helped design when I was an honest scientist. And to spend some time in the control trailer watching the new-fangled computer graphics display data from 800-billion-volt proton collisions is an experience I wish I had time to describe.

Whereas the fixed-target program opens a new realm of parameters for precision and programmatic studies, Tevatron I is the salient into the unknown domain of energies where the potential for fundamental discovery is very large. It will provide the U.S. research community with the highest effective energy in the world, thereby returning the blue ribbon for accelerators to the United States for the first time in more than a decade.

Tevatron I breaks new ground in sophisticated accelerator technology, as it will provide for the head-on collisions of protons and antiprotons in the Tevatron superconducting ring at a total effective energy of 2 TeV, 2 trillion electron volts. This is over three times the energy now being exploited by our CERN colleagues with their pioneering proton-antiproton collider.

Tevatron I is scheduled to have its first shakedown run actually in August of 1985, thanks to some special efforts of the Department of Energy, and to begin a serious physics program in October 1,

1986. We fully expect this project to be completed on schedule and to come within a few percent of its current budget.

Over 300 scientists and students from 16 universities, four national laboratories, and from institutions in Japan, Italy, and France are involved in constructing two major detectors for the Tevatron collider.

Pioneering work on colliders goes back to SLAC in the 1950's with their electron-electron collider. However, the recent work at CERN has been a tour de force of determination and professional expertise. The CERN super-proton-antiproton-synchrotron has made a number of important discoveries and well deserved the 1984 Nobel Prizes awarded to Carlo Rubbia and Simon van der Meer.

At CERN two detectors were constructed to observe the head-on collisions of protons and antiprotons at a total effective energy of about 600 million volts. Much of what was learned there is incorporated in the design of the CDF and the D-Zero detectors at Fermilab.

While the bulk of the financing of these detectors comes from the Department of Energy, significant resources are being contributed by Italy, the NSF, of course, Italy, and especially by Japan. Work on construction of CDF began in 1982 after many years of intense design effort.

The project is about 70 percent complete at this time. The detector is being assembled in a large hall facing a 10-foot-thick steel door that will open to permit this 4,500-ton instrument, composed of Swiss watch intricacies, to roll into the collision hall.

There is a great deal of hope that enough of the detector will be operative by this August to observe some of the collisions that the TEV I people hope to produce in their trials. If both groups are wildly successful, it is possible that some new physics will emerge from this brief glimpse of the world of two TeV. If it does work, it will be over a year ahead of schedule.

Let me comment on the fiscal year 1986 budget. We considered the 1986 budget a good news, bad news story, somewhat along the lines of Herman Postma. The good news is that we are indeed gratified by the confidence bestowed on us by the Department of Energy and the President in what is obviously a very difficult budget year. The bad news may be characterized by the continued shortage of capital equipment funds.

In 1984, after continuous discussions with the Department of Energy, we came to an agreement on a 5-year plan for implementing the utilization of this new facility. We had to take hard action of trimming the program. This involved telling some young physicists that they cannot get on the machine until 1987 or 1988. However, the Department of Energy has not been able to meet this reduced utilization, and the net result is that the Tevatron will come in more like a lamb than a lion. The second detector, D-Zero, will not be ready in 1988, which is where our hopes were, unless the process is corrected dramatically in 1987.

Even our highest priority detector, the CDF, will not be totally complete in 1986. The Fixed-Target Program consists of some two dozen experiments screened from three times that number. It is of exceptional quality. However, it bears the brunt of the shortage of equipment funds. The slowness with which we can implement the utilization of the Tevatron, which is an investment, a total investment, of about $300 million, is obviously something which is to be regretted, and it tends to blunt what should be a robust restoration of U.S. leadership in high-energy physics.

One thing we can appeal to you for is some flexibility in the case of operating versus capital equipment categories. You will remember, Mr. Chairman, last year Dr. Richter and I made a cheerful and absolutely irrefutable appeal for such flexibility.

I would like to close by applauding this committee's initiatives in undertaking the study of Government science policy. I look forward to that study as having very useful results. I would also like to extend an invitation to the committee to visit Fermilab and see how we spend public moneys entrusted to us.

Finally, I would like to leave you with a perceptive quote of the preeminent mathematician and philosopher Bertrand Russell, who said, "We know very little, and yet it is astonishing that we know so much and still more astonishing that so little knowledge can give us so much power."

Thank you.

[The prepared statement of Dr. Lederman follows:]

Statement of Leon M. Lederman
House Committee on Science and Technology
Subcommittee on Energy Development and Application
Hearings on High Energy Physics

February 28, 1985

I. INTRODUCTION

The Fermi National Accelerator Laboratory has a single mission: to do frontier research in the field of Elementary Particle Physics. It is the subjective opinion of the Director that we are entrusted with one of the most significant tasks this nation is engaged in - the elucidation of the workings of the physical universe. This effort has shaped our society in the past, how we live, communicate, our optimism and manifold visions for a greater fulfillment. My colleagues in this field, whose many virtues do not include humility, believe that this subject will continue to influence society in the most profound way; that how we fare in the next decades will be determined by what your Committee and your colleagues decide in these complicated times.

This is a report on the status of Fermilab and of its major project: THE TEVATRON.

Construction started in 1979 after many years of intense R&D on superconducting magnets. The TEVATRON, like Gaul, is divided into three parts, three DOE construction projects. The first project was the construction of the accelerator: the Energy Saver, sometimes also called the Energy Doubler. We'd now like to call it the TEVATRON although we succeeded in both doubling the Fermilab Energy (from 400 GeV to 800 GeV) and in saving electrical energy (50 megawatts reduced to 15 megawatts). The first successful operation of the TEVATRON took place in July of 1983; on October 1 we started our physics program and today, we are operating routinely for physics research - supplying 800 GeV protons to ten targets and an equal number of university-based research teams. I should stress that this is the highest energy accelerator in the world, although the highest effective energy must use head-on collisions and that record is now in Europe.

TEVATRON II is the project which permitted us to upgrade the beam lines and experimental halls to handle up to 1000 GeV protons and to provide the variety of particle probes required for the science we will describe later in this report. This project will be completed on schedule and within budget in FY85 and will provide fourteen beam lines, some new, some simply upgraded to handle the higher energy. The university users of Fermilab will soon have a choice of protons, neutrons, pions, kaons, hyperons, muons, electrons, neutrinos, photons and spin-polarized protons in order to probe the quark substructure of matter. I am speaking of customers from some seventy U.S. institutions and scientists from some twenty foreign countries who are involved in our programs.

TEVATRON I breaks new ground in accelerator technology as it will provide for the head-on collisions of protons and antiprotons ($\bar{p}$) in the TEVATRON superconductiong ring at a total effective energy of 2 TeV. This is over three times the energy now being exploited by our CERN colleagues with their pioneering proton-antiproton collider. TeV I involves the construction of a sophisticated set of storage rings designed to manufacture $\bar{p}$'s, compress them into a magnetic storage device and accumulate enough (100 billion) to inject back into the machines for acceleration to 1000 GeV along with protons rotating in the opposite direction.

TeV I is scheduled to have its first shakedown trial in August of 1985 thanks to some special efforts of the DOE, and to begin a serious physics program on October 1 of 1986. We fully expect this project to be completed on schedule and come in within a few percent of its current budget. Over three hundred scientists and students from sixteen universities, four national labs and from institutions in Japan, Italy and France are involved in constructing two detectors for the TEVATRON collider.

The two major detectors are (1) CDF (Colliding Detector at Fermilab) and D-ZERO. There are several smaller programs which capitalize on the availability of proton-antiproton collisions and these will also be briefly discussed.

Thus we have four major programs underway: (1) The Tevatron Accelerator, (2) the TeV II project and its associated evolving physics program (3) The TeV I proton-antiproton collider project and (4) the Colliding Detector, CDF and D-ZERO. We will discuss the status of each of these briefly in the following and then add some general comments on the theme that "Projects alone do not a Laboratory Make".

Finally, we will comment on the FY86 budget and how our vision is influenced by the Fermilab allocations.

II. The TEVATRON Accelerator

We constructed this machine to open a new domain of observations. We did not realize, in 1979, that this would be an essential prototype of the future of our field, the SSC. In my testimony here last year I told you that this was not an easy machine to build. Superconductivity is still an exotic technology and our work represents by far the most extensive application of this technology and its associated cryogenic engineering ever carried out. We have incidently held several intense briefings for industrial firms, always to full lecture rooms crowded with representatives of General Electric, Westinghouse, Martin Marietta, General Motors, Supercon, Convair, Caterpillar, Combustion Enginering, Oxford SC, Union Carbide and many other great corporations as well as representatives of Japanese and Germany industry coming to see what we did in the name of basic research!

Let me remind you about this accelerator. It is technically called a proton synchrotron.

A synchroton has two main components: Radio-frequency accelerating cavities and guide field magnets. The rf cavities generate electric fields which push the protons to a higher energy. Each time a proton passes through the accelerating cavities its energy is increased by one million electron-volts. In order to rise to an energy of a trillion electron volts the protons must pass through the cavities almost a million times. (They start at an energy of one hundred and fifty billion electron-volts, thanks to a series of injector accelerators consisting of a 750 thousand volt pre-accelerator, a 200 million volt Linear Accelerator, an 8 billion volt Booster and the old Fermilab Main Ring, run at 150 billion volts).

The protons are guided in a circle, back to the accelerating cavities by a ring of superconducting magnets that is four miles in circumference. These magnets are the unique and special feature of the Tevatron. Superconducting magnets are more than twice as strong as conventional copper-iron electromagnets. Superconductivity permits the machine to run at high energy without the use of large amounts of electrical power and allows a one-trillion volt machine to be put in a tunnel which would only hold a 400 billion volt machine if one used conventional electromagnets.

There are 774 twenty-one foot long bending magnts (dipoles) 216 five-foot long focussing magnets (quadrupoles) and almost 1200 correction magnets in this four mile ring. All of these magnets are cooled with liquid helium to just four and a half degrees above absolute zero ($4.5^{o}K$). In order to construct the accelerator the following technical challenges were met:

1. The magnets were built to a precision of a few thousandths of an inch over their entire length. This precision is necessary since one million turns is 4 million miles of travel and the protons must stay within a few tenths of an inch of the perfect orbit!

2. A helium cooling system consisting of 24 refrigerators working together and coupled to a large helium liquefier by a unique helium transfer line was created.

3. A controls system which monitors and controls thousands of functions every second was assembled and programmed.

The controls system, for example, contains over 600 micro computers and 23 large computers all communicating with each other and with the human beings who operate the accelerators. The monitoring system is capable of sensing the position of the protons as they circulate around the ring and sending data to the correction system to allow minute corrections to the orbit in real time.

There are many other complex electro-mechanical systems in the accelerators at Fermilab which have been developed and refined over the years.

All of this equipment is working well at present. Protons are being routinely accelerated to 800 GeV, extracted and delivered. Every 60 seconds a slow, steady 20 second spill of protons is sent to the experimenters who want this type of beam. At the same time, fast 1.5 milli-second spikes of high intensity beam are shipped to the neutrino experimenters (who want quick spurts). The accelerator complex has been delivering beam about 80% of the scheduled time in the past few weeks. This is a very good performance for a relatively new accelerator.

For some experiments, proton beam intensity is as important as high energy. The machine set a new 800 GeV intensity record of over 10^{13} protons per pulse last week.

The Tevatron must not only accelerate and extract beam for fixed target physics, but will also have to store protons and anti-protons for collider experiments. Measurements of the stored beam lifetime are extremely encouraging. The beam will circulate in the beam tube for at last 24 hours.

A very strong focussing system (low-β insertion) has been installed on both sides of the Colliding Detector Experimental Area. This system squeezes the proton and anti-proton beams to a tiny spot at the center of the detector in order to increase the rate of p-$\bar{p}$ interactions. Tests of this system have shown that it works as designed. This is part of the TeV I program, described below.

Of note is the use of the Tevatron for SSC studies. Even though these efforts have been kept at lower priority than the Fermilab experimental program, some interesting observations were possible which may influence the design of the SSC. Measurements were made on the Tevatron which were compared with computer simulations thereby showing the level of predictability. Coasting beam studies demonstrate long lifetimes and lack of strong resonance driving terms. Low energy studies are interpreted as indicating that injection at one TeV peak energy should be possible.

There is still a lot to be done this year and next. The accelerator energy has to be raised from 800 billion electron volts to 1 TeV, but not only in order to justify the name TEVATRON. This will be done by installing a few special bending magnets and by pioneering work to lower the temperature of the ring even closer to absolute zero. At lower temperature, more current can be forced through the magnets so that a reduction of 0.5°K is equivalent to about 100 GeV of increased energy.

The number of protons in the circulating beam will be doubled. This will be accomplished by experiments leading to a better understanding of the dynamic properties of the beam followed by the development of special equipment and methods to control instabilities.

During the coming year intense efforts will be made to improve the reliability of all of the series of accelerators at Fermilab. The key to success on all fronts is smooth, steady running.

If experience is any guide, we have an excellent chance of achieving these goals.

TEVATRON HIGHLIGHTS

FY 85 ACCOMPLISHMENTS

1. First 800 GeV beam
2. First 800 GeV stored beam.
3. New intensity record > 10^{13} protons/pulse.
4. Successful test of low-β insertion.
5. Use of Tevatron for SSC studies.

FY 85 - FY 86 EXPECTED ACCOMPLISHMENTS

1. One TeV beam (1000 GeV)
2. Even higher intensity (-$2(10)^{13}$ protons/pulse).
3. Successful $\bar{p}$-p collisions.

III. TEVATRON II and the Fixed Target Program

This construction project is going extremely well. As the beam lines become ready, the experimenters are already setting up their increasingly complex detection apparatus. It is the opportunities of the physics program that quickens the pulse and brightens the eye. I must confess, Mr. Chairman, that I occasionally play hookey from the Director's Office at Fermilab to spend time with my young friends doing an experiment I helped design when I was an honest scientist. To spend time in the control trailer, watching the new fangled computer graphics display data from 800 billion-volt proton collisions is an experience I wish I could adequately describe.

The core of the Fermilab program is the collection of so-called "fixed-target" experiments. This consists of the extension to higher energies of experiments similar to those carried out in the first decade of the Fermilab research program.

The present experimental program is shown in the appended glossary. It is of large scope, and involves over 600 experimental physicists. Especially significant is the number of graduate students, about 200! Statistically over half of these will, after their Ph.D., fan out into the non-HEP scientific community. This export of exceptional TALENT is a major national (hopefully renewable) resource. The TeV II program may be regarded as comprising about 50% of the U.S. effort in High Energy Physics.

This large participation is prima facie evidence of the scientific importance that the U.S. High Energy Physics community has placed on this program. This is echoed in the consistently high priority placed on the program by numerous HEP review panels down through the years.

It is important to realize that the energy improvement of the Tevatron means much more than just a factor of two in laboratory energy, or 40% increase in center-of-mass energy. This occurs for several reasons:

First of all, in going from 400 GeV to 800-1000 GeV laboratory energy one is crossing the threshold for production of systems containing "bottom" quarks. At the higher energies, the cross sectins are anticipated to be between a factor of 5-10 greater than at the previous energies.

Secondly, there is a major improvement in flux in the secondary hadron beams. This comes about because the higher energy superconducting transport lines accept a much larger bite in transverse momentum than was the case at lower energy.

Also, there is a large improvement in duty factor, i.e. the fraction of time beam is delivered to experiments. This used to be one second out of every ten or fifteen seconds, while in present running it is about twenty seconds per minute. This leads, in many experiments, to a major improvement in data acquisition rate.

It is also important to realize that the relatively low center-of-mass (effective) energy available in these collisions (40 GeV) does not imply a diminished capability in producing forefront physics results. The great diversity of beams and choice of experimental techniques relative to collider experiments allows many unique ways of attacking fundamental physics questions. Most, but not all, of the scientific issues lie within the scope of the highly successful "standard model." While confidence in the correctness of the standard description of quarks, leptons and the forces (strong, electroweak) between them is high, this does not imply the experimental job is done. Challenges to the standard model exist and must be met by more experimentation. Basic parameters need more accurate measurement. The theory of the strong force, quantum chromodynamics (QCD) is very incompletely developed. More experimental data is essential to guide the way.

Experiments at Fermilab address the following diverse set of studies: (1) Weak Forces and the Violation of CP Symmetry (2) Neutrino Physics (3) Properties of Heavy Quarks (4) Hard Collisions of Quarks and Gluons (5) A variety of "other" more difficult to classify experiments, some very speculative, some involving "soft" collisions.

Of the two dozen or so experiments approved for the TEVATRON four have been completed, ten are now taking data and the rest will come on line in 1986, 1987 and 1988.

History has shown that fixed target experimental programs have great longevity. (The discovery of J/ψ at BNL and the SLAC polarized electroproduction experiment of Prescott and Taylor, are singular examples of frontier experiments done more than a decade after commissioning.) The long-range future of Tevatron fixed target physics is likewise bright. The potential physics is extremely good and the opportunities are of high quality.

In the realm of big initiatives we try to foresee, one is a next-generation round of heavy-quark physics. That is, the physics may simply require, just as it has in colliding beams, concentrating most of the effort into a very big centralized facility which might approach collider detectors in size and scope. It may be arguable that existing groups doing charm and bottom physics will be too small, and that the spectrometers being built or exist now are simply not powerful enough to do this kind of physics. Certainly a necessary condition for physics at this level is that a variety of incident beams should be available, not only protons but also neutrons, mesons, hyperons and photons as well. One will need to make comparisons, as well as produce a variety of different kinds of hadrons containing heavy quarks.

At the opposite extreme, there are opportunities for small initiatives within the fixed target program. Examples now discussed or presently pursued include a program on crystal channeling which may even have applications to accelerator physics (including SSC) in providing small septum magnets, measurement of the magnetic moment of omega minus hyperon, quark searches, searches for rare decays, searches for anomalons, and soft muon physics. These have obvious sociological importance in this age of giant collaborations. But they must stand on their own in terms of physics quality.

In any case, the bottom line on the future of fixed target physics is one of commitment. There is much very good physics to be done. The necessary condition is that there be enough resources to match the people, willing to do the hard work to get it out.

IV. The TEVATRON I Project: Colliding Beams

Whereas the fixed target program opens up a new realm of parameters for precision and programmatic studies, TeV I is the salient into the unknown domain of energies where the potential for fundamental discovery is very large.

The Tevatron I Project will provide the United States research community with the highest effective energy in the world, thereby returning the blue ribbon for accelerators to the United States for the first time in more than a decade.

It will combine the most daring technological engineering system ever built in high energy physics, the Fermilab superconducting Tevatron, with an innovative antiprotons source to obtain 2000 GeV, 2 TeV, in the center of mass.

While the Tevatron has been used for 800 GeV fixed target physics for a little more than one year, the tests of the Tevatron as a collider have just begun. When operating as a collider, a beam of protons and a beam of counter rotating antiprotons will be stored in the Tevatron. Typically, both beams will be stored for at least eight hours before they will have to be refreshed with additional protons and antiprotons. Each beam will consist of three one meter bunches circulating over the 4 mile circumference of the Tevatron. The beams will collide at six places and at all but one of these places experimental apparatus will be placed to detect the collisions. At B0, the site of the CDF detector, a system of focussing magnets has been constructed to squeeze the proton and antiproton beams to extremely small diameters, thereby enhancing the collision rate by a factor of 100.

Tests of storing protons in the Tevatron and squeezing the proton beam to its ultimate size have been successfully carried out. The equipment needed to accelerate antiproton and protons simultaneously to 1 TeV is in place and being tested.

The antiproton source, which consists of two small storage rings, the Debuncher and Accumulator, is nearing completion.

Antiprotons are produced in high energy collisions. In the Tevatron I project this will be done by extracting a 120 GeV beam of protons from the old Main Ring, the Tevatron injector, and allowing it to strike a target. A lithium lens will gather the antiprotons and squeeze them in to a beam transport system which will carry them to the Debuncher and Accumulator. The antiprotons will be stored in the Debuncher ring for two seconds. During that time the thickness of the antiproton beam is quickly shrunk by stochastic cooling and then transferred to the Accumulator ring. Here the antiprotons are cooled further, accumulated and stored until needed in the Tevatron. Through this storage period in the Accumulator the antiprotons are cooled by stochastic cooling. The collection power of the Tevatron I Antiproton Source will make it possible to replenish the antiproton beams in the Tevatron every two hours if needed. Antiprotons can be stored in the Accumulator for several days if necessary.

As of February 27, 80% of all of the major components of the source have been installed. It is expected that the remainder of the components will be installed by April. Although the source is not complete, commissioning of the proton beam line which is used to produce the antiprotons has already begun. The target station including its lithium lens is ready for commissioning. Commissioning of the Debuncher ring will be in full swing in April, while the commissioning of the Accumulator will begin toward the end of April. Cooling experiments, the crucial step in bringing the source on line, will start in May.

In May the remaining equipment which is needed to transfer antiprotons from the Accumulator to the Tevatron will be in place. The process of transferring antiprotons to the Tevatron should begin in June.

If all goes well it should be possible to observe collisions of 800 GeV protons or 800 GeV antiprotos at Fermilab before September begins. The collisions will be observed by the massive CDF detector calorimeter.

The project is on schedule for completion in October, 1986. At that time, Tevatron I will be working at full luminosity and energy.

V. The Colliding Detectors

The pioneer work on colliders goes back to SLAC in the 1960's with their electron-electron collider. However the recent work at CERN has been a tour-de-force of determination and professional expertise and the CERN Super-proton-antiproton-Synchrotron (Sp$\bar{p}$S) has made a number of important discoveries and well deserves the 1984 Nobel Prizes awarded to Carlo Rubbia and Simon van der Meer. At CERN, two detectors were constructed to observe the head-on collisions of protons and antiprotons at a total effective energy of about 600 GeV. Much of what was learned there is incorporated in the design of the CDF and the D-Zero detectors.

Both detectors have the problem of trying to sort, out of collisional debris, the gold nuggets of important physics processes. Recall that a proton is a collection of quarks and gluon particles. In the interesting collisions, a single quark in the proton collides with a single anti-quark in the antiproton. However the "spectator" particles also collide peripherally, producing perhaps thirty or more uninteresting particles which burden the detector. To add to the problem, the interesting collision may produce exotic particles like the newly discovered W's and Z's which may in turn decay into neutrinos. These can only be detected by virtue of the fact that there is "missing" energy. These and other detailed considerations about the structure of the radiation emerging from collisions has shaped the Fermilab designs. One important consideration is that they must almost completely surround the collision point, leaving only passage for the vacuum pipe carrying the colliding beams. Since the energies are so high, they must be thick enough in the radial direction to contain the emerging particles. And the thick detectors must be intimately instrumented, giving rise to unprecedented numbers of "bits" of information for each event and an unprecedented demand for computer power to assist in the analysis.

The Collider Detector at Fermilab (CDF) is a general purpose detector system designed to explore the physics of 2 TeV proton-antiproton collisions made possible by the Tevatron I Project. The design, construction, and initial use of this facility is being carried out by a Fermilab-led consortium of physicists from ten U.S. universities (Brandeis University, University of Chicago, University of Illinois, Harvard University, University of Pennsylvania, Purdue University, Rockefeller University, Rutgers University, Texas A&M University, and University of Wisconsin), three U.S. national laboratories (Fermilab, Argonne National Laboratory, and Lawrence Berkeley Laboratory), and groups from Japan and Italy (groups from KEK National Laboratory and Tsukuba University, as well as individuals from several other Japanese universities comprise the Japanese contingent; the Italian groups are from University of Pisa and Frascati National Laboratory.)

Although the bulk of financing comes from DOE, significant resources are being contributed by NSF, Italy and especially by Japan.

CDF cosists of a central magnetic detector that covers the angular range 10° to 170° with respect to the incident proton direction and two forward/backward detectors. The basic goals of the detector include: 1) the measurement of electromagnetic and hadronic energy flow in fine bins of rapidity and azimuthal angle over the entire angular range of CDF with uniform granularity using systems of shower counters and hadron calorimeters, 2) measurements of the directions of charged particles to angles as close to the incident beam directions as technically possible, 3) momentum analysis of charged particles over the angular range 15° to 165°, and 4) identification and momentum analysis of muons over a significant angular range.

Work on construction of CDF began in 1982 after many years of intense design effort. The project is about 70% complete at this time. The detector is housed in a large assembly hall facing a 10 foot thick steel door that will open to permit this 4500 ton instrument (composed of Swiss watch intricacies) to roll into the collision hall, called B-ZERO. There is a great deal of hope that enough of the detector will be operative by August of this year, to observe some of the collisions that the TeV I people hope to produce in their trials. If both groups are wildly successful, it is possible that some new physics will emerge from this brief glimpse of the new world of 2 TeV. If it does work it will be over a year ahead of schedule.

The D-ZERO detector is about three years behind CDF. It has only recently been approved by the DOE after very meticulous review of cost and capability.

The justification for building a second major detector at the Fermilab Collider is two-fold: (1) New results and discoveries must be subjected to confirmation in more than one independent experiment; since the energy regime available at TeV I is attainable in no other machine, a second general experiment is needed. (2) All signs point to an extremely rich harvest of new physics results at the Collider; maximum exploitation of this potential requires a set of detectors with complementary strengths. It is the complementary strength of D-ZERO compared to CDF that is the most powerful argument. This is amply demonstrated by the CERN experience.

There are two classes of phenomena to be studied by the D0 experiment. The first is the examination of known phenomena with predictable improvements in precision. These include a large variety of specific questions, e.g., the Z and W widths and masses, measurements of direct photons, studies of QCD processes, etc. All of these questions bear upon our knowledge of the currently existing models of particle structure and dynamics; the experimental goal in this area is to refine the parameters of these models and even to show the way toward extensions of them by revealing quantitative discrepancies among the parameters. These topics form the knowable backbone of the D0 program. The second class is the new unexplored physics which is opened up by the combination of energy and luminosity increase over the CERN Collider. Here it should be borne in mind that the CERN collider has been enormously fruitful in terms of major new discoveries, owing to the large event rates and the relatively broad-band searches they make possible.

The D0 detector has been designed to take advantage of the experiences of the UA1 and UA2 detectors at CERN. It is a true second generation detector which is also designed to complement and improve on the features of CDF. The detector design stresses uniformity of coverage over the full solid angle with the best available calorimetry. This permits the best possible measurement of jet energies and thus also missing momentum. While CDF (and UA1) use magnetic measurements of tracks, D0 relies on highly segmented calorimetry to discriminate against backgrounds. Elimination of the magnet allows for compact tracking and complete coverage not only for calorimetry, but for muon detection outside.

UA1 and UA2 have been limited in their ability to identify electrons and muons. D0 is the first experiment to incorporate transition radiation detectors in the design to provide extra electron identification, and simultaneously to use a shell of one meter thick magnetized iron around the calorimetry to provide almost complete muon coverage. D0 will have better coverage and identification for either electrons or muons than any existing experiment and is the only experiment to provide both.

Other Colliding Experiments: There are six places around the ring where beams will collide. I have described two of these. In three others, we have smaller experiments designed to look at specific processes. These are: (1) Elastic scattering of protons on antiprotons, taking place at E-ZERO. Here a "bag" of quarks and gluons passes near and sometimes through the corresponding bag of antiparticles and, in some miraculous way, all the quarks and gluons are put back together in each case. How nature succeeds where all the king's horses failed is fascinating science. (2) Under very special circumstances, perhaps induced by the violence of $p\bar{p}$ collisions, the bags confining the quarks and gluons may dissolve, forming a new state of matter, a plasma of quarks and gluons. An experiment at C-ZERO is designed to search for this state. (3) A very speculative search for magnetic monopoles, the cosmologists favorite particle, takes place in F-ZERO.

VI. The Fiscal 1986 Budget

We consider the '86 budget request to Congress a good news-bad news story. The good news is that we are indeed gratified by the confidence bestowed on us by the DOE and the President in this very difficult budget year. The bad news may be characterized by the continued shortage of capital equipment funds. In 1984, after continuous discussions with the DOE we came to an agreement on a five year plan for implementing the utilization of this magnificent facility. We had to take the hard action of trimming the program; this involved telling some young physicists that they cannot get on the machine until 1986 or 1987.

In FY'85, the DOE allocation was $3 million under our guideline ($28 million instead of $31 million) and in FY'86, we are down an additional $3 million. The net result is that the TEVATRON will come in like a lamb rather than like a lion. The D-ZERO detector will not be ready in 1988 unless the process is dramatically revised. Even our highest priority detector, CDF, will not be totally complete in 1986. The fixed target program - some 600 scientists including over one hundred graduate students is a diversified and programmatic attack on the nature of quarks and how they bind to form the materials of our world. Because it consists of some two dozen experiments, screened from three times that number of proposals, it is of exceptional quality. It bears the brunt of the shortage of equipment funds. The slowness with which we can implement the utilization of the TEVATRON, a $300 million investment, is scientifically frustrating, it induces very severe human problems especially among graduate students and post-doctoral researchers and it tends to blunt what would be a robust restoration of U.S. leadership in this important field. Let me not sound too down-beat. We can do good physics in '86. Some flexibility in the operating vs capital equipment categories can certainly be helpful. If you remember, Mr. Chairman, Dr. Richter and I made a tearful and absolutely irrefutable appeal here last year for such flexibility.

VII. The Infrastructure: Projects Alone do not a Laboratory Make

To support the TEVATRON program we should expend a paragraph on the infrastructure. Here we include such activities as R&D on new instrumentation, development of new computer architectures, advances in theoretical physics, the recent addition of an astrophysics group to institutionalize the connection of inner space and outer space, a vigorous technology transfer program via Fermilab's Industrial Affiliates, multiple efforts to improve science education via Saturday Morning High School Physics, Summer Institutes for High School Teachers, Junior High School initiatives, etc. The computer problem deserves some emphasis. It is generally recognized that the computer needs of the TEVATRON will not be met by store-bought computers alone, important as these will be. For this reason Fermilab (as well as SLAC and other university labs) have been developing new, special purpose, parallel processing computers designed to solve the problems posed by the enormous data rates expected from the colliders. I would like to close by extending an invitation to this Committee to visit Fermilab and see how this premier DOE laboratory uses the public monies entrusted to us. And finally I leave you with this perceptive quote of the pre-eminent mathematician and philosopher, Bertrand Russell:

> "We know very little, and yet it is astonishing
> that we know so much and still more astonishing
> that so little knowledge can give us so much power."

Glossary of Approved Experiments in the Fermilab Fixed Target Program

ELECTROWEAK

E-632	WIDE BAND NEUTRINOS IN THE 15 FT. BUBBLE CHAMBER (Berkeley, Birmingham, Brussels, CEN/Saclay, CERN, Fermilab, Hawaii, IIT, Imperial College, MPI/Munich, Oxford, Rutgers, Rutherford-Appleton, Stevens, Tufts)
E-635	SEARCH FOR AXION-LIKE OBJECTS (Fermilab, VPI)
E-636	STUDY OF BEAM DUMP PRODUCED NEUTRINOS (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, ORNL, Seton Hall, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)
E-646	STUDY OF PROMPT NEUTRINO PRODUCTION (Berkeley, Columbia, Fermilab, Hawaii, Rutgers)
E-649	NUCLEON STRUCTURE FUNCTIONS AT HIGH Q^2 (Fermilab, MIT, Michigan State)
E-652	NEUTRINO PHYSICS AT THE TEVATRON (Chicago, Columbia, Fermilab, Rochester)
E-665	MUON SCATTERING WITH HADRON DETECTION (Argonne, Cracow, CERN, Fermilab, Freiburg, Harvard, Maryland, MIT, MPI/Munich, San Diego, Washington, Wuppertal, Yale)
E-733	NEUTRINO INTERACTIONS WITH QUAD TRIPLET BEAM (Fermilab, Florida, MIT, Michigan State)
E-744	NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Chicago, Columbia, Fermilab, Rochester)
E-745	NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, Nagoya, ORNL, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

DECAYS AND CP

E-621	MEASUREMENT OF η_{+-0} (Michigan, Minnesota, Rutgers, Wisconsin)
E-721	CP VIOLATION (Arizona, Athens, Duke, McGill, Northwestern, Shandong)
E-731	MEASUREMENT OF ϵ'/ϵ (CEN/Saclay, Chicago, Elmhurst, Fermilab, Princeton)

HEAVY QUARKS

E-653	HADRONIC PRODUCTION OF CHARM AND B (Aichi, Carnegie-Mellon, Chonnam, UC/Davis, Gifu, Gyeongsang, Jeonbug, Kobe, Korea, Nagoya, Ohio State, Okayama, Oklahoma, Osaka City, Osaka Sci. Ed. Inst., Sookmyong Womans, Toho, Won Kwang)
E-687	PHOTOPRODUCTION OF CHARM AND B (Colorado, Fermilab, Illinois, INFN/Frascati, INFN/Milano, U. Milano, Northwestern, Notre Dame)
E-690	STUDY OF CHARM AND B PRODUCTION (Columbia, Fermilab, Massachusetts, Mexico)

HEAVY QUARKS (continued)

E-691	PHOTON PHYSICS WITH TAGGED PHOTON SPECTROMETER (UC/Santa Barbara, Carleton, CBPF/Brazil, Colorado, Fermilab, NRC/Canada, Oklahoma, Sao Paulo, Toronto)
E-705	CHARMONIUM AND DIRECT PHOTON PRODUCTION (Arizona, Athens, Duke, Fermilab, McGill, Northwestern, Shandong)
E-743	CHARM PRODUCTION IN PP COLLISIONS (Aachen, Brussels, CERN, Duke, Fermilab, Florida State, Coll. of France, Kansas, LPNHE/France, Michigan, Michigan State, Mons, Notre Dame, Strasbourg, Vanderbilt)

HARD COLLISIONS

E-605	LEPTONS AND HADRONS NEAR THE KINEMATIC LIMIT (CERN, Columbia, Fermilab, KEK, Kyoto, Saclay, SUNY/Stony Brook, Washington)
E-672	HIGH P_T JETS AND HIGH MASS DIMUONS (Arizona, Caltech, Chicago Circle, Fermilab, Florida State, George Mason, Indiana, Maryland, Rutgers, Serpukhov)
E-683	PHOTOPRODUCTION OF HIGH P_T JETS (Arizona, Fermilab, Lehigh, Rice, Vanderbilt, Wisconsin)
E-704	EXPERIMENTS WITH POLARIZED BEAM FACILITY (Argonne, Austin, UC/Berkeley, Fermilab, KEK, Kyoto, LAPP/France, LBL, Northwestern, Rice, Saclay, Serpukhov, Trieste)
E-706	DIRECT PHOTON PRODUCTION (Delhi, Fermilab, Michigan State, Minnesota, Northeastern, Pennsylvania, Pittsburgh, Rochester, Rajasthan)
E-711	CONSTITUENT SCATTERING (UC/Davis, Fermilab, Florida State, Michigan)

OTHERS

E-466	NUCLEAR FRAGMENTS (Argonne, Chicago, Chicago Circle, Purdue)
E-508	EMULSION/MULTIPARTICLE PRODUCTION (Cracow, Louisiana State, Tashkent)
E-524	EMULSION/PROTONS GREATER THAN 500 GEV (Washington)
E-576	EMULSION/500 GEV PROTONS (Belgrade, Fermilab, Lund, Lyon, Nancy, Ottawa, Paris VI, Santander, Strasbourg, Valencia)
E-750	EMULSION/MULTIPARTICLE PRODUCTION (Delhi)
E-751	EMULSION/1 TEV PROTONS (SUNY, Buffalo)
E-753	CHANNELING STUDIES (Bell Northern Research, Chalk River, Fermilab, New Mexico, SUNY/Albany)
E-754	CHANNELING TESTS (Case Western Reserve, Fermilab, GE R&D Center, Sandia, SUNY/Albany)

Mr. **Fuqua**. Thank you very much, Dr. Lederman.

Dr. Richter.

[The biographical sketch of Dr. Richter follows:]

BURTON RICHTER—PAUL PIGOTT PROFESSOR IN THE PHYSICAL SCIENCES, STANFORD UNIVERSITY, DIRECTOR, STANFORD LINEAR ACCELERATOR CENTER, STANFORD UNIVERSITY

Born—March 22, 1931.

Education

B.S.—Massachusetts Institute of Technology—June 1952.
Ph.D—Massachusetts Institute of Technology—September 1956.

Employment

Research Associate, High Energy Physics Laboratory, Stanford University, 1956-1960.
Assistant Professor, Physics Department, Stanford University, 1960-1963.
Associate Professor, Stanford Linear Accelerator Center, Stanford University, 1963-1967.
Professor, Stanford Linear Accelerator Center, Stanford University, 1967- .
Technical Director, Stanford Linear Accelerator Center, Stanford University, 1982-1984.

Honors and Awards

Loeb Lecture, Harvard University, 1974.
DeShalit Lecturer, Weizmann Institute, 1975.
E.O. Lawrence Medal (U.S. Department of Energy), 1976.
Nobel Prize in Physics, 1976.
National Academy of Sciences, 1977.

Professional Societies

American Physical Society (Fellow).
American Association for the Advancement of Science (Fellow).
European Physical Society.

Present Committees, Consultantships and Directorships

General Motors Science Advisory Committee.
Mitre Corporation—Jason Group.
Advisory Committee—Max Planck Institute, Munich, Germany.
Accelerator Advisory Committee, CERN, Geneva, Switzerland.
Director, Middlefield Capital Corporation.
Director, Teknowledge, Inc.
Director, Stanford Linear Accelerator Center, Stanford University, 1984- .

STATEMENT OF DR. BURTON RICHTER, DIRECTOR, STANFORD LINEAR ACCELERATOR CENTER, STANFORD, CA

Dr. **Richter**. Mr. Chairman, members of the committee, I appreciate the opportunity to testify before you again. I am going to briefly discuss the status of our new accelerator project, the SLC, and the effect of the proposed budget on our laboratory.

But to put this discussion in context, let me briefly remind you of what we do at the Stanford Linear Accelerator Center. SLAC now operates three accelerator facilities for high-energy physics research, and we're building a fourth. The three that we run now are the PEP colliding beam storage ring at about 17.5 GeV per beam, a low-energy facility, SPEAR, at about 3.7 GeV per beam, and the 2-mile-long linear accelerator at an energy of 32 GeV that's used directly for high-energy physics experiments and also serves as an injector for the other facilities.

The new machine, the SLC, is scheduled to be complete in fiscal year 1986 and when finished, will be the world's highest energy electron-positron colliding beam facility.

In addition to the high-energy physics program, SLAC provides beams for a vigorous syncrotron radiation research program and a nuclear physics program. Half the time of the SPEAR storage ring is dedicated to operation as a syncrotron light source, and in this mode SPEAR is the most heavily used x-ray syncrotron light source in the country.

The nuclear physics program uses special injector facilities on the Linac that allow the production of intense and what for us are low-energy but for nuclear physicists are high-energy beams for nuclear physics studies.

Our accelerators serve 650 physicsts and graduate students in high-energy physics and about 330 scientists and students in other fields in the syncrotron radiation and nuclear physics programs. That's a big chunk of the U.S. science program.

Let me turn now to the SLC, the SLAC Linear Collider. Construction of this project was authorized by this committee in 1983. Construction began in fiscal year 1984, and the project will be completed by the end of fiscal year 1986 if the funds that are recommended in this year's budget submission are appropriated. The project is progressing extremely well, and I am confident that the enthusiastic and talented group of people led by Dr. John Rees, the project director, will succeed in completing the facility within its very rapid 3-year schedule.

Our construction project can be thought of as having two parts. One is all new construction—tunnels, magnets, experimental halls, et cetera. The other is an upgrade of the linear accelerator to raise its energy to the required energy for this project.

The new construction part is all going fine. It's all on schedule. The tunnel is done. The electrical facilities are being installed in the tunnel starting next week. The magnets start moving into it the week after that. And the experimental hall will be finished almost exactly a year from now.

Most of the work on the upgrade of the Linac is also on schedule and doing well, but we did run into one problem, and that problem is connected with our new 50-megawatt klystrons and their associated modulators. The problems with the new tube have been solved. We now have a reliable tube coming out of our klystron production facilities and going on the linear accelerator, but those problems have delayed us and have resulted in some increase in our costs.

Necessary funds for completion are included in the budget, but the TEC for the project has gone from $112 to $115 million, and part of this increase reflects the lower than anticipated first-year funding but about $2 to $2.5 million of it reflects the solution to our klystron problems.

All the rest of the Linac upgrade is doing beautifully, and we do expect to turn the SLC on in October 1986, and we hope to deliver the frst colliding beams to the experimental users in January 1987.

Now let me turn to the question of the fiscal year 1986 budget. I am sure you are very familiar with the story; you have heard it often already. Operating funds in the President's fiscal year 1986 budget for SLAC increased by 4 percent over fiscal year 1985. However, the SLAC cost-of-living index—if I can define such a thing—goes up by 10 percent between fiscal year 1985 and fiscal year 1986.

A very large component of our anomalously high cost-of-living increase comes from a sharp increase in public power costs in California. This increase in power cost is mandated by the Government. It is not connected with new issues of cost recovery for public power which are also included in this next fiscal year's budget. But these things have been scheduled and go into effect in April, and our power budget, were we to do the same amount of operation as we're doing in this year, would go up by nearly 50 percent.

That, coupled with a slightly higher than normal cost-of-living index in the bay area compared to nationally is what makes our CPI 10 percent and the national 4 percent. Thus we're 6 percent short. We've been trying to figure out what to do about it. We will certainly curtail running time. I think we will probably be running about 22 weeks in the next fiscal year. We will probably have to reduce staff. We have to digest this a little bit more and see exactly what will happen.

On the equipment side, my story is very much like Dr. Lederman's. Because of DOE and congressional regulations, equipment funds have to flow to a lot of other things in a big laboratory besides high-energy physics detectors. They range from Xerox machines to fire trucks for the fire department. They all come out of the equipment budget.

SLAC has a problem in equipment funds for we have to run a laboratory and we have to get ready for the turnon of the SLC. After all, this is premier electron-positron colliding beam facility in the world, and it ought to be outfitted to do the physics it was designed to do.

We are building one detector which will be ready at turnon. This in fact is not new construction but is a modification to a detector that was first completed in 1977 and has been used on our lower energy storage ring. It's getting an upgrade, and it's perfectly adequate to get a broad look at the physics that one wants to study in the 100-GeV energy range of the SLC, but it is not adequate to address the entire spectrum of physics questions that you want to study at that energy.

A new detector has been approved by our program committee and has been endorsed by the High Energy Physics Advisory Panel. Our aim was to get it ready in 1989. The time schedule is dictated by the competition. The Europeans will finish a storage ring for electron-positron collision with the same energy as the SLC, although it will cost four times as much as the SLC, and that machine will start in 1989 with four completely modern new detectors designed to study the full spectrum of research at that energy range. We feel that we need a modern full-spectrum machine to keep up with the competition and to do the kinds of physics that this accelerator facility was designed to do.

Let me summarize quickly. The SLC project is going well, and it will be completed on schedule. Operations, we're 6 percent short, and we're trying to figure out what to do about it besides cutting back running time by 4 or 5 weeks. On equipment, our shortfall is about $5 million. At the level earmarked for SLAC in fiscal year

1986 we cannot keep the program going and properly equip the SLC with detectors to match the potential of the machine.

Fermilab, as you just heard, has a similar problem with detectors for the Tevatron collider project. An increase in funds of $8 to $10 million in fiscal year 1986 is required to maintain a schedule leading to completion of detectors for both these facilities in 1989. I don't see how we get there from here with the normal few percent increase in equipment money that has been going on for some years now. It takes a step up in equipment money to get those devices finished and to make both of those accelerators fulfill their potential.

Thank you.

[The prepared statement of Dr. Richter follows:]

TESTIMONY BEFORE THE HOUSE SCIENCE AND TECHNOLOGY SUBCOMMITTEE ON ENERGY DEVELOPMENT APPLICATIONS

B. Richter
Director
Stanford Linear Accelerator Center

February 28, 1985

INTRODUCTION

Mr. Chairman, members of the Committee, I appreciate the opportunity to testify before you again. I will briefly discuss the status of our new accelerator project and the effect of the proposed budget for FY86 on the laboratory. To put this discussion in context, let me briefly remind you of what we do at the Stanford Linear Accelerator Center (SLAC). SLAC operates three accelerator facilities for research in HIgh Energy Physics and is building a fourth. These are the PEP colliding beam storage ring (maximum beam energy 17.5 GeV), the SPEAR colliding beam storage ring (maximum beam energy 3.7 GeV), and the two-mile long Linac (maximum energy 32 GeV) which is used directly for High Energy Physics experiments and also as an injector for the storage rings. The new facility, the SLAC Linear Collider (SLC), is scheduled for completion in FY1986. When finished, the SLC will be the premier electron-positron colliding beam facility in the world.

In addition to its High Energy Physics program, SLAC supplies beams for a vigorous synchrotron radiation research program and a nuclear physics program. Half of the time of the SPEAR storage ring is dedicated to operation as a synchrotron light source and in this mode SPEAR is the most heavily used X-ray synchrotron light source in the country. The Nuclear Physics program uses special injector facilities on the Linac that allow the production of intense, relatively low-energy beams (a few GeV) for nuclear physics studies.

The SLAC accelerators serve about 650 physicists and graduate students in High Energy Physics (35-40% of the U.S. total), and about 330 scientists and students in other fields. Some statistics on users and graduate students are given in figure 1.

I will now return to the main topics of my testimony where there is some good news (on the SLC) and some bad news (on operations and equipment).

THE SLC

Construction of the SLC was authorized by this Committee in 1983. Construction began in FY84 and the project will be complete by the end of FY86, if the funds recommended in the President's budget submission for FY86 are appropriated by Congress. When completed, the SLC will be the world's highest energy electron-positron colliding beam facility and the scientific community is eagerly awaiting the turn-on date and the beginning of the experimental program. The project is progressing extremely well, and I am confident that the enthusiastic and talented group of people led by Dr. John Rees, the Project Director, will succeed in completing this facility within its very rapid three year schedule.

The SLC construction project can be thought of as having two distinct parts. The first part is new construction and involves the mining of approximately 9,000 ft. of tunnel that will contain the 1,000 magnets required to guide the beams from the linear accelerator to the collision point; the guide magnets and their associated equipment; and a large building at the collision point in which experiments will be carried out. The second part of the project involves an upgrade of the existing SLAC linac to provide a system that will produce the required high intensity, low emittance beams of electrons and positrons at an energy of up to 50 GeV.

The new construction is all on schedule. Thanks to the availability of Preliminary Engineering and Design funds from the Department of Energy, we were able to complete the design of the tunnel before the beginning of FY84 and as a result, construction began very rapidly after construction funds became available. The tunnels are now nearing completion. Installation of mechanical and electrical utilities in the tunnel will begin next month and the first of the 1,000 magnets which have to be installed will go in shortly after that. The experimental hall is scheduled for completion almost exactly one year from now and the contractor, who has been on the job for about three months, seems to on schedule.

Most of the work on the linac improvement program has proceeded according to plan. Rather than tell you about all the things that have gone well, I thought I might spend a moment telling you about the difficulties. We have had three problems with the new 50 MW Klystrons and their associated modulators required to get the necessary beam energy in the SLC. First, the tube cathodes procured from industry were not reliable. Our staff worked with the manufacturer and we are now getting a reliable product. Second, the thin ceramic windows that isolate the tube from the outside world would not stand extended operation at the 50 MW power level. We have modified the Klystron design and now use two windows each of which must pass only 25 MW of RF power. Third, the switch tubes used in the Klystron modulators did not last in full power operations. We are procuring new switch tubes from industry. While the problems have been solved, the costs for the Klystrons and modulators have increased. The necessary funds for completion are included in the President's FY86 Budget, but the TEC for the project has increased from $112 to $115.4 million. Part of the increase reflects the lower than anticipated first year funding (FY84).

All other parts of the linac upgrade are proceeding well and we expect to turn the SLC on in October, 1986. We hope to deliver the first colliding beams for the experimental program in January or February of 1987.

OPERATIONS

Operating funds in the FY86 President's Budget for SLAC increase by 4.1% over the FY85 Financial Plan. Total High Energy Physics operating funds are increased by about 5%. The increase earmarked for SLAC is insufficient to cover the increase in the Laboratory cost of living. The reasons for this are as follows.

1. While the increase in the national consumers' price index (CPI) was 4% in 1984, the increase in the CPI was 6% in the San Francisco Bay Area. Note that housing cost increases are not responsible for the difference – the Bureau of Labor Statistics Data indicate that the component of the increase related to housing is about the same in the Bay Area as nationally.
2. Stanford University and SLAC compete with Silicon Valley for labor. Surveys show Silicon Valley is planning an 8% salary increase for 1985, and Stanford cannot fall significantly behind without the potential for loss of key staff.
3. The cost of public power, which is the main component of power used by SLAC, will increase sharply in FY86.

These factors combine to yield an expected "SLAC Cost Index" increase excluding power of about 7% for FY86 and a cost index increase including power of 10% for the same level of operation as will occur in FY85. Thus, there is a shortfall of about 6% between the increase earmarked for SLAC in the President's Budget Submission and the 10% increase required for a level program. We are still evaluating possible responses to this roughly $5 million problem, but it is already clear that running time on the accelerators will have to be curtailed and that some reduction in staff (currently 1425 FTE) may be required.

EQUIPMENT

Because of DOE and Congressional regulations, equipment funds are required for a broad spectrum of items needed at the Laboratory ranging from fire trucks to forklifts to Xerox machines to computers to laboratory instruments to large pieces of high energy physics apparatus. A very lean program for FY86, containing no new physics initiatives for the storage ring and linac programs, requires a base equipment level of $4.7 million. In addition to this base level, three other items are urgently needed.

The first item is an allocation of $2.4 million to complete the upgrade of a detector now in use at the PEP storage ring to make it ready for use at the SLC at turn-on time. This detector (the Mark II detector) was not designed for the SLC energy and, while it will do a good job in the study of the broad features of Z^0 physics, it does not have all of the components required to study the full range of physical phenomena expected at the SLC.

The second item is a new detector required for the SLC designed to match the machines energy and to allow the full spectrum of phenomena expected at the SLC to be studied. This new device, called SLD, has been planned for completion in 1989. It has been strongly recommended by our Program Advisory Committee and endorsed by HEPAP. The timing of this detector facility is dictated by the completion of a competitive machine, the LEP facility at CERN, in late 1988. LEP is expected to have about the same performance as the SLC (at a cost more than 4 times as much) and will be equipped with 4 modern detectors. If the SLC accelerator facility is to remain competitive for the long term, a modern detector is required at about the time that LEP turns on. The SLD has a total estimated cost of around $56 million, including escalation and contingency. About $7 million will come from non-DOE sources (including contributions from Canada, England and Italy). Maintaining the 1989 completion date requires about $7 million from the DOE in FY86.

The third item is an upgrade to the PEP storage ring to increase its intensity. PEP began operating in FY81, and has performed quite well. An increase in intensity is required to extend the useful life of this facility by allowing experiments to look at more subtle physics phenomena (estimated cost $2.5 million).

Thus, the FY86 needs (in millions of dollars) are as follows.

Minimum Base	4.7
Mark II Upgrade	2.4
SLD	7.0
PEP UPGRADE	2.5

If the President's Budget is passed as submitted to Congress, $11.3 million will be earmarked for SLAC, leaving a $5.3 million shortfall. We cannot significantly compromise the Mark II detector, for we must have an experiment ready when the SLC is ready. Thus, the PEP upgrade and the SLD facility will have to be slowed.

CONCLUSION

SLC The SLC project is going well and will be completed on time if the funds recommended in the President's FY86 budget submission are appropriated.

Operations The SLAC operations budget is about 6% ($5 million) short of funds required to maintain the FY85 level of operations. We will have to cut back running time on the machines and may have to decrease staff.

Equipment The SLAC shortfall in urgently needed Equipment funds is about $5 million. At the level earmarked for SLAC in FY86, we cannot keep the present program going and properly equip the new machine, the SLC, with detectors to match the potential of the machine. Fermilab has a similar problem with detectors of its Tevatron collider project. An increase of equipment funds of $8-10 million in FY86 is required to maintain a schedule leading to completion of detectors for the new U.S. accelerator by 1989. This increased level of equipment funding will have to be maintained through FY89 to properly equip the new U.S. frontier of accelerators with the detectors needed to make proper use of the investment in the machine.

THE SLAC USER COMMUNITY IN 1984

	PHYSICISTS	GRADUATE STUDENTS	INSTITUTIONS
HEP -- EXPERIMENTS NOW RUNNING	275	87	52
HEP -- ANALYZING DATA FROM COMPLETED RUNS	119	21	25
HEP -- BUILDING NEW EXPERIMENTS	169	31	33
TOTAL HEP (DUPLICATIONS ELIMINATED)	496	149	
SYNCHROTRON RADIATION USERS PER YEAR	225	60	
NUCLEAR PHYSICS USERS	40	8	

Fig. 1

Mr. FUQUA. Thank you very much.

Dr. Samios.

[The biographical sketch of Dr. Samios follows:]

BIOGRAPHICAL SKETCH OF DR. NICHOLAS P. SAMIOS

Born March 15, 1932, New York, New York.
1949—Stuyvesant High School.
1953—A.B. Columbia College, Physics.
1957—Ph.D. Columbia University, Physics.
1956-59—Department of Physics Columbia University, Instructor.
1970—Present—Department of Physics Columbia University, Adjunct Professor.
1969-75—Department of Physics Stevens Institute of Technology, Adjunct Professor.
1959-62—Brookhaven National Laboratory Department of Physics, Assistant Physicist.
1962-64—Brookhaven National Laboratory Department of Physics, Associate Physicist.
1964-68—Brookhaven National Laboratory Department of Physics, Physicist.
1965-75—Brookhaven National Laboratory Department of Physics, Group Leader, Nuclear Interactions Group (Changed to "New Group").
1968-Present—Brookhaven National Laboratory Department of Physics, Senior Physicist.
1975-81—Brookhaven National Laboratory Department of Physics, Chairman.
1981—Brookhaven National Laboratory High Energy and Nuclear Physics, Deputy Director.
Jan. 1982—Brookhaven National Laboratory, Acting Director.
May 1982-Present—Brookhaven National Laboratory, Director.

Awards

1980—E.O. Lawrence Memorial Award for leadership in the study of elementary particles, in particular for the discovery of the Omega minus particle and the first charmed baryon.
1980—New York Academy of Sciences Award in Physical and Mathematical Sciences.

STATEMENT OF DR. NICHOLAS P. SAMIOS, DIRECTOR, BROOKHAVEN NATIONAL LABORATORY, UPTON, NY

Dr. SAMIOS. Thank you. It is a pleasure to testify before this committee. I will focus my testimony on three issues: One, the current status of Brookhaven National Lab's High-Energy Physics Program; a few brief comments on the transfer line; and last, the impact of the 1986 budget on the state of the Laboratory as a whole.

As you see, I have zero hats on. I should be wearing two, but I really have two since we do high energy and we are a multidisciplinary lab.

Now, the High-Energy Physics Program at Brookhaven is centered around the ultragradient syncrotron. This is a 30-GeV proton accelerator which accelerates 1.5 times 10-13 protons per second. It has a complement now of the order of 450 university laboratory users, about 85 Brookhaven and the rest from the university community.

In my prepared testimony I go through the physics. I would just like to comment on two points. One, the sophistication of physics these days is such that at Brookhaven we can detect events as rare as one in 10^9 or 10^{10}. That has great ramifications in being able to investigate a mass scale that's in the multi-TeV mass range. In fact, to paraphrase one of our theorists, he said, "It would be fun to find the smoking gun for one TeV physics 10 years before you see the dead bodies at the SSC." I think that's a nice turn of phrase.

Second, we have an active program in neutrino physics, where one of the important issues is the question of neutrino mass. To give you a scale, we have detectors that are 300 tons with a detector a kilometer away from where the neutrinos are produced. We have a program pursuing that.

The proposed operating budget in high-energy physics has a 3-percent increase, going from 1985 to 1986 for Brookhaven, and taking into account inflation and power costs, corresponds to a slight decrease in effort. This will have the effect of restricting the program to roughly the same level. We will attempt to keep it at the same level as last year, where we had anticipated increasing to 35 weeks.

In addition, comparable to my illustrious directors to my left, we also have a slight capital equipment problem which will slow down several of these large detectors which are going to investigate these rare K decays.

The most serious deficiency for Brookhaven, however, is the omission in the 1986 budget of the proposed booster upgrade of the AGS. This is a project which has gone through the accepted and prescribed DOE procedures and was initially proposed by DOE for construction in fiscial year 1986. However, this booster proposal did not survive the OMB-DOE deliberations into the final 1986 budget.

This upgrade consists of an addition of a fast-cycling 1-GeV proton ring which is interposed between the presently existing 200-MeV linear accelerator and the AGS. Its main attribute is that it will increase the proton intensity by a factor of 4. A few experiments such as I mentioned, the neutrino investigation, could use this intensity even at the present time, either to do the experiment faster or to get more data.

However, this factor of 4 is of greater importance to the broad range of approved AGS experiments which will be ready to take data in the next few years. Although the intensity of the AGS has been increased from 10^{11} to 10^{13} protons, two orders of magnitude, since its inception, the user demands and the richness of the program, especially the rare K decays, now require this further improvement.

Again, its nonimplementation will cause delays, some severe, in the execution of the already approved program. The addition of the booster will require only nominal increases in personnel or operating funds. The total construction costs for this booster project is $24.6 million over 3 years, with an initial request for $6 million in fiscal year 1986. Our highest priority at BNL is the restoration of this booster for fiscal year 1986.

The transfer line is going fine. It's a $10 million project for 1985-86. We've committed and expended of the order of $6 million out of the $10 million. In my prepared testimony you have the time line and all the details. We anticipate no problems with that project.

Finally, I would like to summarize the effect of the proposed 1986 budget as it pertains to the general state of the Laboratory as a whole. As you are aware, Brookhaven is a multidisciplinary lab with 3,000 people and more than 1,000 outside users who carry out research in the physical and life sciences as well as the applied areas. Although all the numbers are not in, the best information that we now have available indicates a reduction of 2 percent in the total laboratory operating budget. Some programs have modest increases, most have slight reductions, and others have zeroed out or major decreases.

Although I have outlined a number of unmet needs for fiscal year 1986, let me reassure you that I and my colleagues appreciate the need to reduce the large national deficit and understand the difficulty of your task. However, I want to stress the very long-term nature of most of our research efforts which suffer greatly when unplanned cuts are made. The decrease of momentum, the loss of expert staff and severe morale problems which usually accompany such occurrences have an effect much larger and longer lasting than might be expected from a short-term retrenchment.

Thus, although the present budget will diminish our research efforts, we shall make every effort to operate our facilities at the 1985 level and to keep personnel reductions to a minimum. Our requests for additional funds—namely, for the booster—are made to maximize the unique long-term contributions of Brookhaven to the nation's scientific efforts.

Thank you.

[The prepared statement of Dr. Samios follows:]

TESTIMONY OF DR. NICHOLAS P. SAMIOS
BROOKHAVEN NATIONAL LABORATORY

It is a pleasure to testify before this Subcommittee on Energy Development and Applications. I will focus my testimony on three issues: the current status of Brookhaven National Laboratory's high energy physics program, the relativistic heavy ion research program that will use the Tandem/AGS transfer line project, and the impact of the FY 1986 budget on the state of the Laboratory as a whole.

The high energy physics program at BNL is centered around the Alternating Gradient Synchrotron. This is a 30 GeV proton accelerator which accelerates $\sim 1.5 \times 10^{13}$ protons every second. It has had an illustrious history, having produced several Nobel prize experiments and provided a huge body of data that has led to a greater understanding of the fundamental particles that exist in nature and of their interactions. The present research effort includes in addition to 85 BNL experimenters, 340 University users from 45 Institutions (including that famous university at Tallahassee) participating in a broad based experimental program. I will only mention here two of the most exciting and unique investigations being actively pursued at the AGS. The first involves an exploration of the multi-TEV mass range, the same range to be explored directly by the superconducting super collider. The present discovery of the W and Z^o bosons in Europe provided solid evidence for the unification of electromagnetic and weak interactions. The now standard picture of the fundamental constituents is that they consist of 6 leptons and 6 quarks with the forces between them being due to exchanges of these W's and Z's and gluons. This picture, however, is unsatisfactory in that it includes a large number (17) of arbitrary constants. Among these are the masses of all these "fundamental" particles, with the further open question of how to unify all the forces, strong, electroweak, and finally gravitational.

There has emerged a variety of conjectures and models called supersymmetry, technicolor, etc., many of which either predict numerous new particles or even that the quarks themselves are composite. One way to test such ideas is to build higher energy accelerators (SSC) and produce such particles. We also have, however, an opportunity now to search for very rare processes that can only occur if such conjectures are valid. It turns out that the parameters of the AGS are very appropriate for producing large numbers of K mesons (of the order of 10^{11} or 10^{12}/year) which are ideal for such studies. Because of great improvements in experimental techniques it is now possible to measure events occurring as rarely as once in 10^{11} or 10^{12} times. Experiments have been approved to look for several different decay modes: The first type of approved experiments involves reactions such as (1) $K^0 \rightarrow \mu^{\pm} e^{\mp}$, (2) $K^+ \rightarrow \pi^+ \mu^+ e^-$ and (3) $K^+ \rightarrow \pi^+ \nu\bar{\nu}$. These experiments are to be conducted at the AGS over the next three to four years. Examples of (1) and (2), if found, will imply the existence of new particles of mass ≃ 60 TEV. Reaction (3) has the additional good quality of being expected to occur under the standard model, at a rate 10^{-11}; deviations from this expected number (some speculations yielding values as large as 10^{-9}) would indicate the existence of new massive particles.

The second type of approved experiment involves neutrino mass. Up to recent times neutrinos were thought of as massless spin 1/2 particles traveling at the speed of light. There have been several experiments performed suggesting that the electron neutrino may indeed possess a finite mass. A figure of merit for probing such a possibility is ℓ/E_ν, where ℓ is the distance between the production and detection of the neutrino and E_ν is the neutrino energy. One wants to make this number as large as possible and at BNL a 300 ton detector has been placed at a distance $\ell \sim 1$ kilometer from the accelerator, which produces neutrinos with energy $E_\nu = 1$ GeV. The program devoted to the study of neutrinos and their interactions is especially appropriate for the AGS at BNL and extends the range of exploration carried out elsewhere by an order of magnitude.

The proposed operating budget in high energy physics has a 3.1% increase in FY 1985 to FY 1986 which, taking into account inflation and power costs, corresponds to a slight decrease in level of effort. This will have the effect of restricting AGS operations at or below the 30 week level of 1985 (in contrast to the anticipated increase to 35 weeks). In addition shortages in the capital equipment fund will slow down the construction of one or possibly two of the large experiments looking for rare K decays mentioned above. The most serious deficiency is the omission in the FY 1986 budget of the proposed booster upgrade of the AGS. This is a project which has gone through the accepted and prescribed DOE procedures and was initially proposed by DOE for construction in FY 1986. However, this booster proposal did not survive the OMB-DOE deliberations into the final FY 1986 budget. This upgrade consists of the addition of a fast cycling 1 GeV proton ring which is interposed between the presently existing 200 MeV linear accelerator and the AGS. Its main attribute is that it will increase the proton intensity by a factor of four. A few experiments, such as the aforementioned neutrino investigation, could very effectively use this intensity even at the present time, either to do the experiment in a shorter time or to obtain more data in a given length of time. However this factor of four is of greater importance to the broad range of approved AGS experiments which will be ready to take data in the next few years. Although the intensity of the AGS has been increased from 10^{11} protons/pulse to 10^{13} protons/pulse during its existence, the user demands and the richness of the program, especially the rare decay searches, now require this further improvement. Again its non-implementation will cause delays, some severe, in the execution of the already approved program. The addition of the booster will require only nominal increases in personnel or operating funds. The total construction cost for this booster project is $24.6M over three years with an initial request for $6M in FY 1986. Our highest priority at BNL is the restoration of the booster for FY 1986.

The transfer line connecting the BNL Tandem Van de Graaff and the AGS was approved for construction for FY 1985 and FY 1986 at a total cost of $10.4M. The main purpose of this facility is to introduce ions up to masses of sulphur (A=32) into the AGS and accelerate them up to an energy of 15GeV/AMU. The intent and expectation is to produce nuclear matter at densities 5 to 10 times ordinary nuclear matter and to explore the consequences. A user community of three to four hundred physicists has expressed interest in this physics and five experiments have already been approved, with six more to be considered this March. The status, construction timeline, commissioning schedule and cost summary are noted in the accompanying tables. The bottom line is that everything is going well and that we are at present within a few weeks of schedule. Pictures of the layout and the ongoing construction are appended. The construction funding profile shows that $6M has already been expended or committed to date and we are optimistic on the remaining bid package. The only slightly negative note is that we project the beam commissioning and physics run to be delayed by several months, this latter activity to early FY 1987. This is due to the insufficient operating funds allotted to BNL in nuclear physics in FY 1986, a shortfall of several million dollars from the requested funding rate. Otherwise we are pleased with progress to date, with no major problems or difficulties foreseen at this time. I should also like to note that the booster upgrade mentioned earlier will have the added positive feature of allowing the acceleration of ions from sulphur A=32 up to atom masses of A=200, indeed very heavy ions in the AGS, thereby greatly increasing this experimental capability at essentially no added cost.

Finally I would like to summarize the effect of the proposed FY 1986 budget as it pertains to the general state of the Laboratory as a whole. As you are aware Brookhaven is a multi-disciplinary Laboratory with 3000 people and more than 1000 outside users who carry out research in the physical and life sciences as well as applied areas. Although all numbers are not in, the best information that we now have available indicates a reduction of 2% in the total Laboratory operating budget. Some programs have modest increases, most have slight reductions, and others have been zeroed out or have major decreases.

Although I have outlined a number of unmet needs for FY 1986, let me assure you that I and my colleagues appreciate the need to reduce the large national deficit and I understand the difficulty of your task. However, I want to stress the very long-term nature of most of our research efforts which suffer greatly when unplanned cuts are made. The decrease of momentum, the loss of expert staff and the severe morale problem which usually accompany such occurrences have an effect much larger and longer lasting than might be expected from such a "short-term" retrenchment. Thus, although the present budget will diminish our research efforts, we shall make every effort to operat our facilities at the 1985 level and to keep personnel reduction to a minimum. Our requests for additional funds are made to maximize the unique, long-term contributions of Brookhaven to the nation's scientific efforts.

TANDEM/AGS HEAVY ION PROJECT

- STATUS -

TANDEM MODIFICATIONS

INTERSHIELD FOR MP-7	INSTALLED/CONDITIONING
ION SOURCES	TESTING

BEAM TRANSFER LINE

BEAM OPTICS	COMPLETE/REVIEWED
DIPOLE MAGNET SYSTEMS	ORDERED
QUADRUPOLE MAGNETS	ORDERING IMMINENT
VACUUM SYSTEMS DETAILED DESIGN	IN PROGRESS
MAJOR COMPONENTS	ORDERED
INSTRUMENTATION EVALUATION	IN PROGRESS

AGS MODIFICATIONS

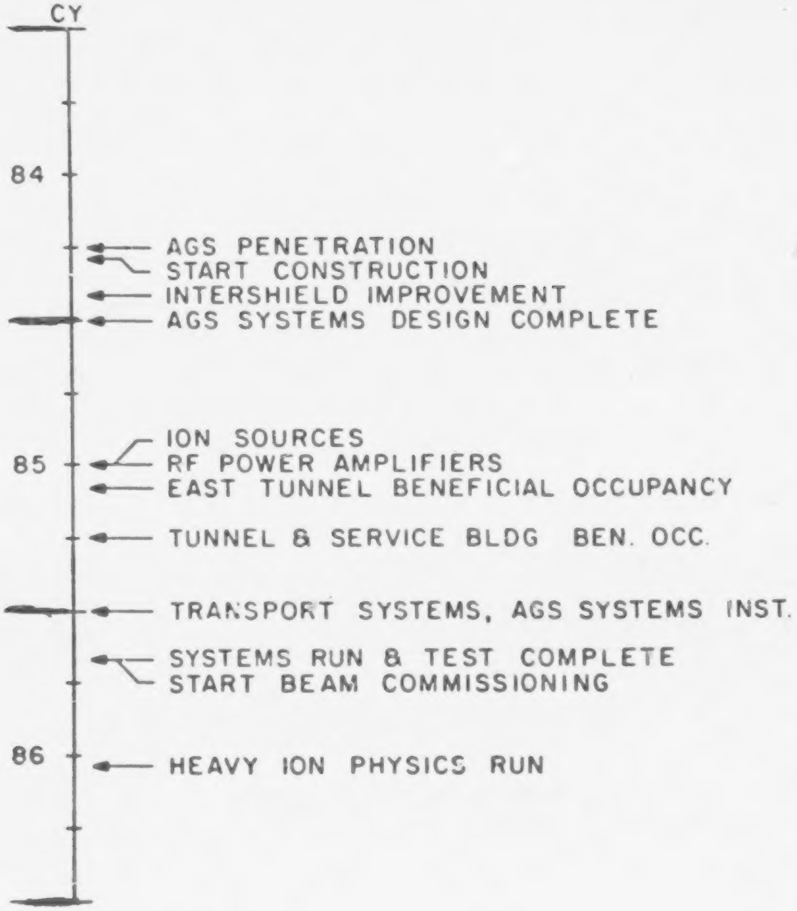
INJECTION SYSTEM FABRICATION	IN PROGRESS
RF SYSTEM TESTS + DETAILED DESIGN	IN PROGRESS
MAJOR COMPONENTS	ORDERED
CONTROLS DETAILED DESIGN	IN PROGRESS

CONVENTIONAL CONSTRUCTION

TUNNEL EXCAVATION	IN PROGRESS
AGS PENETRATION	COMPLETE

TANDEM/AGS HEAVY ION PROJECT

CONSTRUCTION TIMELINE


CY
84
AGS PENETRATION
START CONSTRUCTION
INTERSHIELD IMPROVEMENT
AGS SYSTEMS DESIGN COMPLETE
ION SOURCES
85
RF POWER AMPLIFIERS
EAST TUNNEL BENEFICIAL OCCUPANCY
TUNNEL & SERVICE BLDG BEN. OCC.
TRANSPORT SYSTEMS, AGS SYSTEMS INST.
SYSTEMS RUN & TEST COMPLETE
START BEAM COMMISSIONING
86
HEAVY ION PHYSICS RUN

HEAVY ION BEAM COMMISSIONING

GOAL

HEAVY ION BEAMS 14.6 GeV/AMU O^{16} S^{32}	JUNE 1986

COMMISSIONING OUTLINE

TRANSPORT & AGS SYSTEMS INSTALLATION COMPLETE	DECEMBER 1985
TANDEM BEAMS O^{16} COMMISSIONING COMPLETE	JULY 1985
S^{32} COMMISSIONING COMPLETE	DECEMBER 1985
BEAM TRANSPORT AND AGS SYSTEMS RUN & TEST	FEBRUARY 1986
TANDEM BEAMS TO AGS	MARCH 1986
*INJECTION ORBITS AND CORRECTIONS	APRIL 1986
*CAPTURE AND ACCELERATION	MAY 1986
*EXTRACTION & SWITCHYARD 14.6 GeV/AMU	JUNE 1986
START OF PHYSICS RUN O^{16}	JUNE 1986
(S^{32}	JULY 1986)

*THESE COMMISSIONING PROGRAMS ARE INTERSPERSED WITH PROTON PHYSICS RUNNING.

TANDEM/AGS HEAVY ION PROJECT
- SUMMARY -

[AY $ (1000)]

	10/84 PLAN	2/85 EXP. & COMM. TO DATE	2/86 EST. COST AT COMPLETION
ACCELERATOR SYSTEMS	$ 4,151	$2,010	$ 4,151
CONVENTIONAL FACILITIES	3,588	3,441	3,477
ARCHITECT ENGINEER	329	329	329
ENGINEERING, DESIGN, INSPECTION, ADMINSTRATION	1,217	204	1,217
SUBTOTAL	9,285	5,984	9,174
CONTINGENCY	1,015		1,126
TOTAL	$10,300		$10,300

MVH

PANEL 4—DISCUSSION

Mr. **Fuqua**. Thank you very much.

Dr. Lederman, the high-energy physics programs throughout DOE has about half a billion dollars, and you've been in the meeting this morning and afternoon and repeatedly members have indicated, you know, we've got severe budget deficits and so forth and how do we do that. How do we justify to our constituents the spending of a half billion dollars for high-energy physics?

Dr. **Lederman**. Well, sir, I think in some sense, several of my colleagues before tried to give an answer to this. I think the brief answer is that, in my own viewpoint, there are two arguments.

One argument has to do with the historical statement that we believe in the future of this country. We believe the country has a future, and we do believe it because we spend hundreds of billions of dollars on defense and hundreds of billions of dollars on education, and certainly that's an investment which takes 20 to 40 years to pay off.

If we believe in the future of the country, we have to make a heavy investment in basic research, of which high-energy physics is one component. If we want to get out of the budget deficits and the crises of the 1990's and beyond, somehow, and if we have faith that the country will survive till then, we cannot be deterred by local crises which come all the time. If we read back in the history of hearings before this committee and before its predecessors, there is a litany of special economic situations which put pressure on the basic research budget, and there's nothing more harmful and more costly than a cycle of ups and downs in the support of basic research.

I think we need a steadiness and we need confidence that if the applications of the SSC, which Mr. Tigner was up against the wall trying to define, if those applications are not profound, it will be the first time in history that such an advanced scientific thrust does not impact on society.

The other thing is—and it's something which I have tried to document in a Scientific American article—is the spinoffs of the kind that Mr. Postma showed you, the artificial joints and so on, that continuous flow of technological innovations. I think if one studies that, one sees that the cost to the treasury of the investment of the moneys in high-energy physics and other basic research is paid back by a continuous increase in the GNP and taxes paid to the Treasury just from the spinoffs. If it's not all of the basic research budget, it's a major fraction. I think it's the biggest bargain the American public is getting.

Mr. **Fuqua**. There was a study a few years ago that took the basic and applied research—I think it was by Chase Econometrics—that had a payback after about 4 years of about 7 to 1 to the GNP.

There was a similar study, totally separate, in Europe, that had a similar conclusion. That is probably about 10 years ago that I am aware of that study, but I would imagine that it's still as true today as it was at that time.

Dr. **Lederman**. There is a new study that just came out of CERN, a new econometric study of CERN as an economic utility. That study has just been published and reconfirms that older report, of something like a 7-to-1 return.

I hope your forthcoming investigation of science policy really tries to quantify these things and establish them once and for all.

Mr. FUQUA. Thank you.

Dr. Richter, you were quoted in your prepared statement to the ERAB panel that we seem to be in some danger in high-energy physics of always building and never doing. Does that mean that you believe there is an imbalance in the program at the present time?

Dr. RICHTER. I think at the present moment, yes, there is. We have—and I think it's due to a failure in planning, really. We plan to build new accelerator facilities and we build them and we build them beautifully and we get them done on time. Somehow or another, when you figure how you're going to use those accelerator facilities plus the other things you have, our planning never seems to include getting together the resources necessary to exploit the tools that we build.

This is particularly true in detectors. We don't have any mechanism that identifies for Congress when a machine is approved for construction what the detectors are going to cost, although we do indeed identify to the Department of Energy what we think they're going to cost. It's very difficult to identify those costs precisely as we do with the accelerators. The accelerators have huge design studies and detailed engineering studies before we start construction, and detectors aren't in that stage. You don't want to start the detectors before you start the machinery or you'll be building obsolete detectors.

We need some mechanism to at least recognize that our new accelerator facilities are going to need detectors and are going to need support and to at least put a rough number on them so that Congress and the administration knows clearly what they're getting into when they start a project like Tevatron I or the SLC or the biggest of them all, the SSC.

Mr. FUQUA. Dr. Samios, the operating budget that's been assigned to Brookhaven, how is that going to impact you as far as employment? Will you have layoffs, and, if so, about what magnitude?

Dr. SAMIOS. I would say if you look at it labwide, if you take that 2-percent cut, although we haven't done the detailed studies but knowing the rules of thumb we would guess it will be a minimal impact, but something of the order of 100. There would be a reduction of staff of about 100 out of the 3,000.

Mr. FUQUA. Mr. Mineta.

Mr. MINETA. Thank you very much, Mr. Chairman.

Dr. Richter, earlier I had asked some of the others, I guess it was Dr. Trivelpiece, as to whether or not there was too much control centralized in terms of the budget, given the budget constraints, whether or not there was some other way to work at this. And the one that seems to come up every so often is this interchange or allowing the directors to be able to shift funds between operating and capital budget.

I was wondering if that kind of flexibility is something that would be helpful to you at the local level.

Dr. **Richter**. I think that would be helpful to me. I am sure it would be helpful both to Dr. Lederman and to Dr. Samios also.

We have argued for it before. The problem has always been that Congress has very zealously guarded its prerogative to allocate construction, capital, and operating costs. And I think some flexibility to move a reasonable amount around within not only high-energy physics but the same problem exists in other energy research programs, too, would be good in getting the optimum program out of what is a very tight budget year.

Mr. **Mineta**. Now, if the high-energy physics budget for fiscal year 1986 were to be held constant——

Dr. **Samios**. You mean constant where it is now or constant between 1985 and 1986? There is a big difference.

Mr. **Mineta**. The $35 million.

Dr. **Samios**. To be restored?

Mr. **Mineta**. What would the impact be at SLAC?

Dr. **Richter**. Well, it depends on what you did with it. If I had my druthers and had that $35 million to distribute, I would chop it up into roughly three equal pieces and earmark one of those pieces for detectors for the new accelerator, another piece for increasing operations, and a third piece for getting more industrial R&D going on the SSC.

If that happened, we would get our detector for the SLC done on schedule in fiscal year 1989, and I think that we would be able to restore operations back to what they are in fiscal year 1985 instead of cutting them back, and I am sure that we would not have to reduce personnel at the laboratories.

I never thought I would see the notion of an absolute freeze from one year to the next look so attractive as it does this year.

Mr. **Mineta** [presiding]. I have no other questions. But I guess I am chairing now, until Mr. Fuqua returns.

I have no further questions, unless staff has any questions.

[No response.]

Mr. **Mineta**. If not, then thank you very much for your patience. The subcommittee stands adjourned.

[Whereupon, at 2:40 p.m., the subcommittee was adjourned.]

[Questions and answers for the record follow:]

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 · Batavia, Illinois · 60510
312-840-3211 FTS 370-3211

Directors Office

March 27, 1985

Dr. Harlan Watson
Subcommittee on Energy Development
& Application
Committee on Science & Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Bldg.
Washington, D.C. 20515

Dear Harlan,

In response to the letter of the Chairman here are the answers to the hearing questions posed by the Subcommittee. I would be happy to elaborate on any of these, especially Question 1 which is a hobby but takes lots of work.

Sincerely,

Leon

Leon M. Lederman

Enclosure

Response to Questions: Subcommittee on Energy Development and Applications

Dr. L. M. Lederman

1. How are the results of high energy physics contributing to other branches of science. What branches of science need the results from high energy physics to get on with their goals?

   There are two ways in which High Energy Physics (HEP) influences other sciences: (1) Through the instruments and facilities which are invented and used in HEP and (2) through the intellectual content of the science and the theoretical techniques invented. Both techniques have had decisive influences, in recent times, on materials science, on structural biology, on fusion research, on nuclear physics, on chemistry and on all aspects of astronomy.

   a. Synchrotron Radiation. This is derived from high energy circular accelerators (synchrotrons). These were designed, proposed and built for HEP research. The first synchrotrons were built at Cal Tech (1.5 GeV) and at Cornell (2.2 GeV) in 1953. The 12 GeV Cornell synchrotron started running in 1967. These were all frontier HEP machines. The first storage rings in the U.S. was SPEAR (1972, 2.2 GeV) although an earlier version looked at e^-e^- collisions. Both the electron synchrotron and the storage rings were HEP inventions, designed to explore the electromagnetic interactions of fundamental particles.

      Light sources are now operative at SPEAR (Stanford), Wisconsin, Brookhaven and Cornell. The users include:

      Biologists who use soft x-ray microscopy and also time-resolved microscopy to study live specimens in an atmospheric environment with very high resolution and chemical element discrimination. The subnanosecond time resolution permits observation of conformal changes in biological materials. With HEP drift chambers, molecular structure of great complexity can be resolved. Protein crystallography is prominent.

      Chemists and metallurgists use x-ray fluorescence to do trace element analyses; soft x-ray absorption spectroscopy is applied to determine the structure of catalysts. Invaluable models of structure and surface processes are determined.

      Materials Science is part of the above and includes amorphous materials science, tunable UV is used to study chemical bonding and electronic structure at semiconductor-metal interfaces.

      One can go on and on. See Synchrotron Radiation Research, Ed. R. Winick and S. Doniach, Plenum Press, 1980.

      As you know, Materials Research (see Major Facilities for Materials

Research and Related Disciplines: National Academy Press, 1984: Seitz/Eastman Report) has, as its first priority, a 6 GeV Synchrotron Radiation Facility.

b. Electron Accelerator. Another version of "last year's" HEP machine is the first priority for Nuclear Science as described in the Report by the DOE/NSF Nuclear Science Advisory Committee. December 1983 and the subsequent 1984 report of the Vogt Committee, convened by OSTP. Here the first priority is a 4 GeV, CW electron accelerator. The second priority for construction is a relativistic heavy ion collider, again a machine which would not have been possible without the high energy accelerator development.

c. Instruments. High Energy instrumentation has had a very strong influence on almost all fields of research. The PET scanner, a crucial biomedical instrument was invented by Alan Cormack, a high energy physicist skilled in the use of photomultiplier crystal particle detection.

Proportional Wire Chambers and the associated electronic readout are widely used in nuclear physics research, in space probes and in medical diagnostics. Spark chambers are used in the burgeoning field of gamma ray astronomy.

Superconducting magnets of large size were constructed in HEP laboratories soon after the invention of hard superconductors (in materials science!). Large bubble chamber magnets were built in BNL and Argonne in the mid-1960's. This experience and the associated cryogenics were directly applicable to the large SC magnets used in Fusion research: i.e. Large Coil Project at Oak Ridge and the Livermore Mirror Machine. More recently the materials developed in industry to supply Fermilab's TEVATRON have been applied to NMR imaging magnets.

d. Applications of HEP physics results and theoretical techniques
(1) A reading of the Nuclear Science Advisory Committee report indicates how much this discipline is drawing from HEP. Look at some subheadings: II.5 Quarks and QCD in nuclei, II.6 Strangeness in Nuclei, II.7 The Electroweak Interaction and Beyond. One of the major goals of SURA is to search for the effects of the quark structure of protons and neutrons as the energy density of nuclear matter is increased in high energy collision.

(2) The Astrophysics of the early universe is practically merged with HEP. At the temperature of the first instants after the big bang, matter was decomposed into its most primordial forms - exactly these forms studied in high energy collisions. Other applications have to do with neutrinos in super nova dynamics, black holes, neutron stars, etc.

(3) In Condensed Matter Physics, the language of quantum field theory

and Feynman graph techniques are used as a unifying framework for solid state analysis. In fact, there is a periodical: Field Theory and Statistical Systems (Nucl. Sci B, North-Holland) devoted to the interface of particle theory and solid state science.

(4) Electroweak theoretical techniques and in particular soliton solutions of non-linear equations have been applied to polymer physics and chemistry.

(5) Mathematics gains from developments in the supersymmetry work, especially in the theory of Lie algebras.

(6) Computer Science gains from the intense development of parallel processing technology carried out by theorists interested in lattice-guage theory calculations.

(7) Hydrodynamics gains and breakthroughs in the theories of turbulence have come from techniques associated with the renormalization group.

Names like K. Wilson and M. Feigenbaum are now well known to experts in fluid dynamics.

(8) Many high energy physicists have gone on to achieve eminence in other fields: just to count Nobel Laureates, scientists trained in HEP have won Nobel prizes in Biology (W. Gilbert), Medicine (A. Cormack) and Peace (A. Sakharov).

2. In the FY 1986 budget request, Fermilab had the good fortune to receive the only new construction start in the Department's basic research program, its Central Computer Upgrade. Could you tell us why this upgrade is so important?

In the fall of 1986, Fermilab will carry out its first collider experiment, observing the collisions of protons on antiprotons at a total CM energy of close to 2 TeV.

Also in 1986 and 1987, the TEVATRON fixed target program will be providing beams to about twelve major research experiments, all specifically designed to exploit the new TEVATRON energy. As director, I convened a panel of experts early in 1983 (Ballam Committee) to advise the Laboratory on the computer requirements engendered by the TEVATRON program. Although we were on safe ground in extrapolating the fixed target needs, the estimation of collider impact was greatly aided by the experience at CERN. Here, the $\bar{p}p$ collider, operating at a luminosity of 1% of Fermilab's design, was using a major fraction of the total computing power of that great Laboratory.

The Ballam Committee estimated that we would need about five times the presently available capability in order to keep pace with the data appearing early in calendar 1987. (24.5 Cyber 175 equivalents). Simply stated, without a major new acquisition, the data analysis would be hopelessly mired and the scientific productivity of the TEVATRON stalled.

In order to have a new acquisition reasonably operative for the 1987 research, a start on the computer center by October 1985 is obviously essential. A casual visit to the Fermilab site would be eough to convince anyone that the new acquisition must be housed in its own enclosure.

3. How much financing has Fermilab received from Japan and Italy for the construction of the Collider Detector (CDF)? Will there be international collaboration in the construction of the D-Zero detector?

The collider detector (CDF) construction has been assisted greatly by the contributions (both scientific and financial) of the Japanese and Italian collaborations.

Through the Japanese fiscal year 1985 (i.e., April 1, 1986), direct contribution from Japan will total $10,040,000 not including the personnel costs of the Japanese scienctific staff working on this project. In addition to the above, the Japanese have supplied the superconducting solenoid for the detector which is estimated to cost at least $2,500,000.

The Italian contribution through the Italian fiscal year 1984 has been $1,850,000, again not including the 61 man-years of personnel costs so far supplied by Italian collaborators in the technical support of the project.

International collaboration in the construction of the D-Zero detector has been initiated by a commitment on the part of a group from CERN/Saclay in France to furnish approximately $1.2 M towards construction of apparatus. This contribution is in addition to the support provided by their physicists. Collaborations are being discussed with other European groups but no other agreements have yet been reached.

4. What funding profile in each of FY 1986, FY 1987 and FY 1988 is required if the D-Zero is to be ready to operate in 1988?

The required funding profile for D0 to be operative for the 1988 collider run would be the following:

1986	1987	1988
$ 9M	$ 16M	$ 11M

5. We sent you a copy of the Committee's Science Policy Task Force's Report, An Agenda for a Study of U.S. Science Policy. Would you like to comment on the Report? What important issues concerning the government laboratories in general and your laboratory in particular do you believe should be included in the Task Force's study?

I have read with great admiration, the Report of the Task Force on Science Policy. I find it very inclusive and really can think of no issues which have been omitted except the issue of science literacy of the general public. I do have a few comments which may be included here although I would suppose that opportunities for more significant input will appear in the future. My comments use the Proposed Agenda enumeration.

IA1. One must always include the important role of training of cadres of new innovators in any "pay-off" consideration.

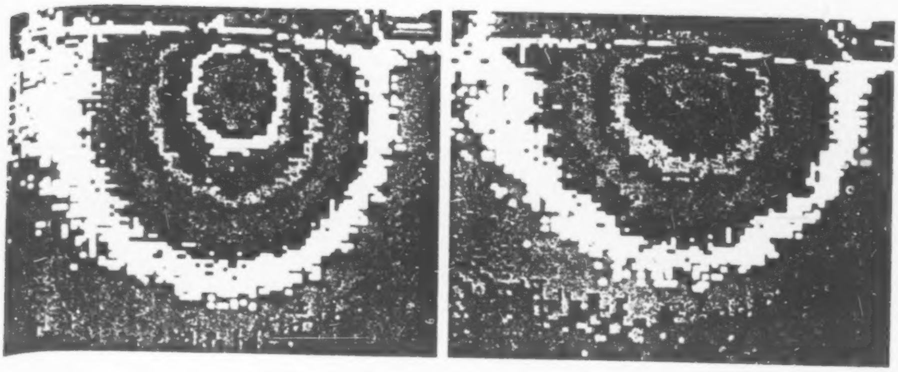
IC2, IIE, VII D1 Here, the delicate balance of International Cooperation and Collaboration should be thoroughly analyzed. This should be done with D-pay-off in mind since collaboration involves compromise with pay-off e.g. in technology transfer to industry. The case of SSC is a good one to illuminate the issues.

IE2,3 The Task Force should be aware of the CERN economic study: Economic Utility Resulting from CERN Contracts (CERN 84-14 December 84).

III A3 The role of national labs in education has been a grass-roots effort and may well be considered for expansion.

VII D Priorities: It would be useful for the Task Force to explore mechanisms for setting priorities as between different science disciplines, especially for large, shared facilities.

IX B1 It may be that the recent increase in tendency to go around peer review be discussed in some depth.



Materials Science Research
Physics Today

interference from background radiation

Synchrotron radiation research

The development of synchrotron-based research has been driven by the development of ever-increasing source flux and brilliance. (Flux is the total photon rate per unit bandwidth per unit area at the sample, while brilliance is the photon rate per unit source area per unit solid angle per unit bandwidth.) Generally, experiments that do not require highly collimated beams—such as photoemission spectroscopy and studies of extended x-ray-absorption fine structure—have signal rates proportional to source flux, while experiments that require highly collimated beams and small sample areas—such as surface diffraction studies—have signal rates that scale with source brilliance.

As sources have developed from high-energy facilities used parasitically to rings specially designed for higher brilliance, the scientific results they have produced have become more and more important. For example, uv photoemission spectroscopy has elucidated electronic structure, gas phase spectroscopy has contributed to the study of excited atomic and molecular states, and soft x-ray lithography has become an important technology (see figure 3). The high brilliance and high flux of synchrotron x-ray sources have allowed experimenters to use EXAFS techniques in studying grain boundaries in alloys, active sites in catalysts and the local structure of amorphous materials and biological materials. Small-angle scattering has advanced to permit time-resolved studies of various materials phenomena, such as phase separations in multicomponent glasses and crazing in stressed polymers (figure 4). Further development of the sources has allowed x-ray scattering techniques to be so refined that one can now study directly the structure of microcrystals only 1 micron on a side, and even crystal surfaces. While x rays scatter very weakly from magnetic structures—the scattering is 10^{-6} times that of ordinary Bragg scattering—one can now examine x-ray magnetic scattering with higher resolution than neutron scattering, and medical researchers are beginning to use synchrotron radiation for imaging coronary arteries.

▶ Angle-resolved photoemission has become to the electronic structure of materials what x-ray scattering is to crystal structure and what neutron scattering is to phonon structure. One can use angle-resolved photoemission to determine the three-dimensional (bulk) or the two-dimensional (surface) band structure of most single crystals. The unique capabilities that are available with a polarized, tunable, and intense radiation source allow the experimenter to tune to any part of the two- or three-dimensional band structure and to determine the orbital symmetry of each state. One can then use these experimental symmetries to determine band symmetries of the bulk material, orbital characters of the surface states, and bonding orientations of adsorbed molecules. Electronic-structure measurements have been made on such materials as simple metals and semiconductors, transition metals and rare earths, compound semiconductors and alloys, and intercalated graphite and layered compounds.

Measurements of angle-resolved photoemission from surfaces of single crystals have revealed in detail the character of the two-dimensional electronic states for surfaces bearing adsorbed atoms or molecules or carrying bulk impurities segregated to the surface. Not only can one observe the electronic state of the adsorbate–substrate bond, but one can also measure the adsorbate–adsorbate interaction—either directly or through the coupling to the substrate. An excellent example of this type of work is the detailed examination of the bonding of H to the surface of Pd or Ti crystals, or the bonding of S segregated to the surface of Fe crystals.

▶ Surface x-ray diffraction techniques are quite new, but substantial progress has been made, and the future potential of this technique is clear. Measurements made so far include determinations of the reconstructed surfaces of Ge(100), Si(111) and InSb(111); studies of adsorbate structures such as Pb and O on single-crystal Cu, and Kr and Xe on single-crystal graphite; work on thin liquid-crystal films and thin amorphous layers, and time-dependent studies of recrystallization following laser annealing. It is now well established that available x-ray fluxes from insertion devices (that is, wigglers and undulators) permit studies of single atomic layers of materials with low scattering power. The wide range of systems available for study therefore includes essentially the entire periodic table (except H and possibly He). There have been successful studies of systems with opaque substrates and with transpar-

Principal synchrotron sources

Location	Energy (GeV)	Type
USA		
National Bureau of Standards	0.28	dedicated
Cornell University	5.5	parasitic
University of Wisconsin	0.24	dedicated
	0.8	dedicated
Brookhaven	0.75	dedicated
	2.5	dedicated
Stanford	4.0	parasitic
	15.0	parasitic
LBL	1.3	dedicated*
(Various proposals)	6.0	dedicated*
Japan		
Tokyo	0.3	dedicated
Tsukuba	2.5	dedicated
	0.6	dedicated
Okasaki	0.6	dedicated
England		
Daresbury	2.0	dedicated
France		
Orsay	0.54	dedicated
	0.8	dedicated
	1.8	dedicated
Germany		
Hamburg	5.0	parasitic
Berlin	0.8	dedicated
Italy		
Frascati	1.5	parasitic
USSR		
Moscow	0.45	dedicated
Karkhov	0.1	dedicated
Novosibirsk	0.7	parasitic
	2.5	parasitic
	5.0	parasitic
China	2.8	dedicated*
India	0.8	dedicated*
Taiwan	1.0	dedicated*
USSR	2.5	dedicated*
Europe	5–6	dedicated*

*Proposed

Principal neutron sources

Location	Type
USA	
Brookhaven, HFBR	reactor
Oak Ridge, HFIR	reactor
Argonne, IPNS	spallation
Los Alamos, WNR	spallation
National Bureau of Standards	reactor
Canada	
Chalk River	reactor
France	
Grenoble, ILL	reactor
Grenoble	spallation*
Saclay	reactor
England	
Rutherford-Appleton Lab., SNS	spallation
Denmark	
Risø	reactor
Japan	
Tsukuba	spallation
Tokai	reactor
Germany	
Julich	spallation*
Munich	reactor
Berlin	reactor

There are many smaller reactors throughout the world where some neutron scattering is carried out. We have listed only the major sources of this type.

*Proposed

ent substrates, and of freely suspended systems with no substrates. The penetration of x rays also has been shown to allow the study of structures below the surfaces and at interfaces.

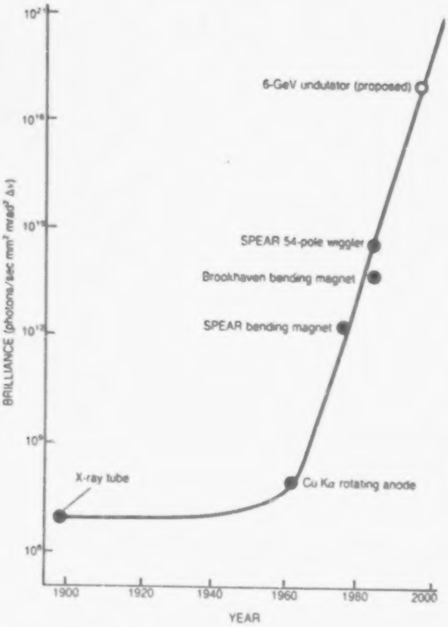
▶ X-ray lithography is still in its development stages, yet it represents a significant commitment in the programs for synchrotron-radiation research, both in the US and abroad. In the US most of the efforts have centered on 1:1 contact lithography, where the ultimate objective is to integrate x-ray lithography into a semiconductor processing line for fabricating VLSI circuits. In addition to working on circuit applications, researchers are also studying structures having a very high aspect ratio. Synchrotron radiation has recently also been used to study the spectral response of sensitized photoresists; the resulting data will be especially useful to determine the imaging quality of soft-x-ray optics for future x-ray projection printers. In Europe, x-ray lithography is also a very active field, and semiconductor processing facilities are being integrated into synchrotron-radiation facilities.

▶ Magnetic x-ray scattering shows the promise of complementing traditional neutron-scattering studies. For example, recent experiments have shown that the sample volume can be up to six orders of magnitude smaller than required for an optimal neutron experiment, and calculations show that it may be possible to study surface magnetism. Furthermore, the high intrinsic collimation of synchrotron radiation makes possible excellent wave-vector resolution (that is, with Δq on the order of 10^{-4} Å^{-1}). Such resolution is essential in studies of incommensurate magnetic structures. Finally, the polarization dependences of the cross section permit not only the separation of charge scattering and magnetic scattering, but also the separation of orbital and spin contributions. It is clear that x-ray diffraction experiments using synchrotron radiation will ultimately make significant contributions to the field of magnetism.

A new synchrotron source

The enthusiasm of researchers in condensed matter for the construction of a new synchrotron facility (recommended with the highest priority by the Major Materials Facilities Committee) stems both from the technological opportunity to produce dramatically brighter x-ray beams and from anticipating the results that will certainly flow from research at such a source. Before we discuss these research opportunities, we will mention the key points in the technical rationale for a new facility. The starting point is the understanding of the consequences of the spectral effects produced by undulator magnets. Figure 5 schematically represents the history of x-ray brilliance; figure 6 shows what is now the brightest beam in the world. Undulators clearly represent an enormous gain over current synchrotron sources. Instead of the broad fan of radiation with a continuous spectrum produced by bending magnets and wigglers, the constructive interference that takes place in an undulator produces radiation whose spectrum peaks at a wavelength λ_p (and its harmonics) and which is collimated into a solid angle $d\Omega$ given by $2\lambda_p/L_u$, where L_u is the undulator length. The wavelength λ_p at which constructive interference occurs is given approximately by $\lambda_u/2\gamma^2$, where γ is the electron energy in units of mc^2, and λ_u is the undulator magnet period. (This expression is quite different[4] from that for the critical wavelength of bending magnet radiation.) To produce undulator radiation peaked at 20 keV ($\lambda_p = 1$ Å) with a reasonable undulator period, one thus requires an electron energy of about 6 GeV. This energy level represents the first requirement for a new machine.

There is a second requirement for the machine that stems from the highly collimated nature of undulator radi-



Brilliance of x-ray sources as a function of time, as indicated by some important devices. The most recent sources marked on the graph are a parasitic bending magnet at Stanford, a bending magnet at Brookhaven's low-emittance ring, and the 54-pole wiggler at SPEAR. (The unit bandwidth Δν is 0.1%.) Figure 5

ation. For a peak wavelength of 1 Å and an undulator 2 m long, we find that the beam is emitted into a solid angle $d\Omega$ of 10^{-10} rad²—a spectacularly small divergence: The beam will pass through a 200-micron pinhole some 20 m from the undulator. To achieve this high collimation, the undulator must be installed on a "low-emittance" storage ring, that is, a ring with a small, highly collimated electron beam. Fortunately, progress in storage-ring design made over the last 10 to 15 years offers the possibility that rings based on current technology can have both crucial properties.

We should make one final point before discussing the scientific opportunities of a new synchrotron. A 6-GeV ring, while optimized to produce hard x rays, would also produce longer-wavelength radiation of high brilliance. In fact, beams of wavelengths shorter than about 100 Å would be more brilliant on a 6-GeV source than on any existing lower-energy storage ring. A high-energy storage ring is therefore expected to serve users representing a broad spectral range.

Scientific opportunities

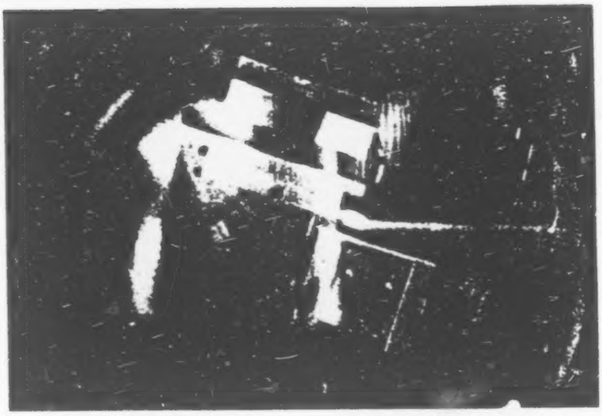
The scientific opportunities for the 6-GeV ring fall into four well-defined categories. The first category contains all the unanticipated research that emerges once the facility is in use. Inevitably the most exciting and far-reaching discoveries made with newly developed experimental tools are those that were not predicted. To confirm this view, one need look no further than the preconstruction vision of what physics was likely to emerge from the SPEAR storage ring. Not only was the J/ψ particle unpredicted, but no one had imagined how useful SPEAR would be as a synchrotron-radiation facility. The gain in brilliance provided by the proposed 6-GeV undulator beam is so substantial that unanticipated work will be a large—perhaps the largest—component of the work to be done a decade from now.

The next category contains the research we anticipate doing but cannot now accomplish for lack of the special properties of undulator radiation. Condensed-matter phenomena generally have both a temporal and a spatial scale. An example would be the energy–momentum relation (dispersion curve) of a phonon mode in a crystal. Currently, x-ray experiments involve an energy-transfer resolution of less than 1 eV and a momentum-transfer resolution generally poorer than 10^{-3} Å^{-1}; their real-space resolution is generally poorer than 100 microns, and their time resolution is generally longer than about a nanosecond. The x-ray undulator, however, will permit us to work *routinely* in regions not currently accessible to experiments.

Two examples demonstrate how techniques based on the 6-GeV undulator will permit improved resolution:

▶ The x-ray microprobe, in which microfocused x rays are used for spectroscopic studies of the elemental constitution of matter. Calculations show that a 6-GeV undulator microprobe would have an advantage of at least 10^3 in detectability over the state-of-the-art electron microprobe; it would be able to resolve spatial variations at the 500-Å level. This level of spatial resolution is a direct consequence of the brilliance of radiation from an undulator. When one realizes that approximately $1 billion is invested nationally in electron microprobes, the scale of the potential impact of a factor of 10^3 in minimum detectability becomes clear.

▶ Inelastic x-ray scattering from solids. Neutron scattering is at present the preferred technique for resolving meV (that is, thermal-energy) excitations in solids. The best x-ray energy-transfer resolution available with techniques based on current sources is about 0.1 to 1.0 eV. It may be possible to use spherically bent crystals in a back-scattering geometry to obtain resolutions of 10^{-2} eV. If so, one can at best hope to demonstrate the potential of the method on existing synchrotron sources. The proposed low-emittance 6-GeV source will, however, be sufficiently powerful that x-ray inelastic scattering can become as routine as neutron techniques. Of course, x-ray scattering has advantages over neutron scattering in some cases. For example, the x ray couples directly to electronic excitations, and it is considerably more sensitive to surface features; high-energy transfer is much more easily accomplished with x rays, and essentially no kinematic restrictions prevent access to the low-momentum–high-energy-



The brightest photon beam in the world is produced by the Exxon–LBL–SSRL 54-pole wiggler at the Stanford Synchrotron Radiation Laboratory. Here it is entering the monochromator tank and striking the first of a pair of perfect silicon crystals. The beam shows up as fluorescence in the helium gas that fills the tank. (Photo by H. Morales and S. Brennan.) Figure 6

transfer regime of interest in amorphous systems and liquids. Another spectacular possibility for inelastic scattering involves the development of nuclear-resonance scattering to provide monochromatic x-ray beams with submicrovolt resolution. In principle a 6-GeV undulator source with appropriate instrumentation would allow for inelastic scattering with an energy-transfer resolution of 10^{-7} eV.

We turn now to the third category of opportunities for the 6-GeV ring: extensions of existing techniques. Scattering experiments of various sorts are the primary beneficiaries of increased brilliance because they generally require high flux, good collimation and small beam size in varying degrees. High flux is necessary for studying materials with low atomic number, for studying samples with few scattering particles (such as atomic microclusters) and for performing time-resolved experiments. Good collimation is necessary in scattering experiments for studying long-range order and structures having large length scales, and for accurately varying the incidence angle (and, therefore, the penetration depth) of the beam. Small beam size is necessary for studying small crystals or materials in restricted volumes (as in high-pressure experiments), for diffraction microscopy and for studies involving glancing-angle diffraction.

We finally arrive at the last category: the science that could result from radiation sources at the new facility other than x-ray undulators. Although x-ray undulators are the primary scientific goal, the 6-GeV ring would have the standard complement of bending magnets which could support a large number of beam lines, perhaps doubling the nation's capacity for application of well-developed synchrotron techniques: EXAFS, surface EXAFS, powder diffraction, low-resolution microprobes, small-angle scattering, crystallography, surface diffraction and time-resolved studies.

A 6-GeV synchrotron would have an impact on experiments involving the electromagnetic spectrum from roughly 100 eV to 10 keV, providing from two to four orders of magnitude more brilliant illumination. Given the history of photons in condensed-matter research, the scientific success of such a facility is assured.

Consequences

Thirty years ago Rudolf Peierls wrote[5] in the preface to his book on theoretical solid-state physics, "The quantum theory of solids has the reputation of being rather less respectable than other branches of theoretical physics." He explained that this was the consequence of the use of extremely simple single-particle approximations to make the connection between microscopic and macroscopic phenomena. This situation has radically changed in the intervening years. The development of the many-body theories of superconductivity and superfluidity and the microscopic understanding of phase transitions has placed the theory of condensed materials in the intellectual forefront of physics, with high-energy and nuclear physicists often using theoretical results from condensed-matter physics. But the payoff has been far greater than Peierls could have imagined. Not only is the intellectual core of condensed-matter physics as deep and exciting as any branch of physics, but the impact of this knowledge—and the methods used to obtain it—in other branches of science and technology is enormous. Condensed-matter science, broadly construed, provides the scientific basis of our high-technology society. Among the key experimental methods that have driven this explosion of knowledge are the studies of the space–time correlations of phenomena in condensed matter, which have used electron, neutron, and electromagnetic probes. The continued development of facilities for these probes will keep condensed-matter science in both the intellectual and technological forefront.

* * *

We would like to thank J. D. Axe and C. J. Sparks for their contributions to this article, and R. J. Birgeneau and H. Winick for their thoughtful reading of the manuscript and their helpful comments.

References

1. G. H. Vineyard, L. Falicov, Rev. Sci. Instrum. 55, 57 (1984).
2. *An Assessment of the National Need for Facilities Dedicated to Synchrotron Radiation*, NAS, Washington, DC (1976). *Current Status of Facilities Dedicated to the Production of Synchrotron Radiation*, NAS, Washington, DC (1983). *Current Status of Neutron Scattering Research and Facilities in the United States*, NAS, Washington, DC (1984). Ames Laboratory, *Report of the Review Panel on Neutron Scattering*, IS-4761, Ames, Iowa (1980). National Synchrotron Radiation Planning Committee, *Planning Study for Advanced Synchrotron Radiation Facilities*, Sandia National Laboratories, Albuquerque, New Mexico (1984).
3. *Major Facilities for Materials Research and Related Disciplines*, NAS, Washington, DC (1985). See also PHYSICS TODAY, September, page 57.
4. A. Bienenstock, H. Winick, PHYSICS TODAY, June 1983, p. 48. This article gives a complete discussion of wigglers and undulators.
5. R. E. Peierls, *Quantum Theory of Solids*, Oxford U. P., London (1954).

□

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

Mail Address:
SLAC, P.O.Box 4349
Stanford, California, 94305

March 14, 1985

The Honorable Don Fuqua, Chairman
Committee on Science and Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Fuqua:

I am responding to your letter of March 5*th* which asks for answers to a few questions raised by members of the Subcommittee to supplement the record of the Hearing of February 28, 1985 at which I testified.

The first question concerned the funding profile of the SLD detector in FY86 through FY89, if that detector were to be completed in FY89. The Table below gives this information.

SLAC Equipment Needs for SLD
Completion in FY89
(Millions of Then Year Dollars)

	FY86	FY87	FY88	FY89
SLD Total	9.0	19.8	17.7	7.4
Foreign Contribution	1.0	0.6	0.6	0.6
NSF Contribution	0.4	0.6	0.6	0.7
Net DOE for SLD	7.6	18.6	16.5	6.1
Other SLAC Needs	9.7	11.4	9.4	10.0
Total SLAC	17.3	30.0	25.9	16.1

The Table includes the total SLD funding requirements as well as the net contribution needed from the Department of Energy after subtraction of expected foreign contributions and NSF contributions. I have also included a line giving other SLAC needs through this period to arrive at the last line – total SLAC equipment needs including those for the SLD. You may be interested to know that the foreign contributors in order of decreasing contribution are Canada, Italy, and England.

The next question asked about the impact of a reduction of machine running time in FY86 on the Research Program at the Stanford Synchrotron Radiation Laboratory (SSRL). SSRL pays one-half of the cost of operating the SPEAR storage ring and a share of the cost of operating the Linac, which serves as an injector into the storage ring, based on the fraction of Linac pulses that they use. Thus, I would guess that the SSRL running time would be reduced in proportion to the reduction of SLAC running time unless SSRL's budget can afford the enormous increase in Linac operation costs associated with being the sole user of the machine and can afford to pay a larger than normal fraction of the SPEAR operations cost.

The third question asked where I would like the laboratory to be ten years from now. There are three main things that I would like to see.

(a) SLAC should remain a world-class center in high energy physics experiments, theory, and apparatus development.

(b) The advanced accelerator R&D program should have developed a conceptual framework and a technology to allow the construction of advanced, very high energy electron colliders in a practical and cost-effective manner.

(c) SLAC should assist other scientists in other disciplines to exploit the special opportunities that arise from our high energy physics facilities (for example, Nuclear Physics and Synchrotron Radiation work,) and to construct those facilities for these other disciplines that require our special expertise.

To accomplish the first of these two goals will require brains, vision and hard work from our staff and adequate funding from the government. The accomplishment of the third goal may require the creation of something somewhere between a single purpose laboratory and a multipurpose laboratory – for want of a better phrase I might call it an allied purpose laboratory. We should be involved only in those things where there is some unifying thread, i.e. our accelerators.

Your last question asked for comments on the Report of the Task Force on Science Policy. I have read the Report and I think it is an excellent job. The outline of the proposed study is quite thorough and addresses the issues which I think have to be included in any review of science policy.

Sincerely,

Burton Richter

Burton Richter, Director
SLAC

BR:kmc

bnl
aui

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, Long Island, New York 11973

(516) 282 } 2772
FTS 666 }

Office of the Director

March 19, 1985

The Honorable Don Fuqua, Chairman
Committee on Science and Technology
U. S. House of Representatives
Washington, D.C. 20515

Dear Mr. Fuqua:

Thank you for your letter of March 5 concerning my testimony before the Subcommittee on Energy Development and Applications on February 28. I appreciate the opportunity to respond to the questions raised by Members of the Subcommittee and enclose my answers herewith.

Sincerely yours,

N. P. Samios

N. P. Samios
Director

NPS/hbs

Enclosures

BROOKHAVEN NATIONAL LABORATORY

Response to Questions of the
Subcommittee on Energy Development and Applications
FY 1986 DOE Authorization for Basic Research
February 28, 1985

1. How does BNL's overall budget projected for FY 1986 compare with the current year's budget? Please present a program by program comparison of BNL's actual and estimated funding for FY 1984, FY 1985 and FY 1986.

   BNL's budget projection for FY 1986 compared to FY 1985 is essentially flat dollars. A program by program comparison of the FY 1984, 1985 and 1986 funding for operations, capital equipment and construction is appended.

2. Is the proposed Booster upgrade of the AGS a natural and evolutionary step toward the eventual development of a relativistic heavy ion collider at Brookhaven?

   The proposed Booster upgrade of the AGS is indeed a natural and evolutionary step toward the development of a relativistic heavy ion collider at Brookhaven. Its salient strengths are: a) It can be built and tested without disturbing the ongoing AGS program. This is due to the fact its major components are geometrically external to the presently existing facilities. b) As noted in my testimony, it (the Booster) has unique capabilities for high energy physics increasing the proton intensity by a factor of 4 and the polarized proton intensity by a factor of 20, thereby allowing for the implementation of a rich and forefront scientific program (some details on the unique physics opportunities are noted in my testimony). c) The presently approved and funded nuclear capability at the AGS will provide for the acceleration of nuclei up to an atomic number of A=32 (sulphur) and up to an energy of 15 GeV/nucleon. The Booster upgrade will extend this 15 GeV/nucleon capability from A=32 (sulphur) to A=200 (gold is A=198) and provides a unique fixed target heavy ion capability and the concomitant exciting new physics. The RHIC (Relativistic Heavy Ion Collider) will in turn use the Booster produced ions as a starting point for the acceleration of ion species up to A=200 and up to energies of 100 GeV/nucleon. The BNL design accommodates these goals and the Booster upgrade is an ingredient, a step in supplying the capability between A=32 and A=200 which is deemed essential to all studies of relativistic heavy ion physics especially at RHIC.

3. On page 3 of your testimony, you note that the proposed Booster upgrade of the AGS "has gone through the accepted and prescribed DOE procedures." What are these "accepted and prescribed DOE procedures"? Has this project been considered by HEPAP? Has HEPAP formally endorsed this project?

The accepted and prescribed DOE procedures involve the consultation and involvement of the BNL user community in the evolution and approval of the final proposal by the BNL Management and AUI, presentation of the proposal to the Office of Energy Research of the DOE, presentation to HEPAP, (a technical and cost review by DOE panels) and subsequent submittal by DOE of a Schedule 44 to OMB and Congress. The Booster upgrade proposal followed the above procedures and in addition underwent outside technical review commissioned by the BNL management, was approved by the BNL Directorate, and was presented and supported by the AUI Board of Trustees.

The AGS Booster is a logical extension to the AGS and guarantees that the investment in BNL scientific facilities will continue to produce outstanding science. It is a cost effective $25M upgrade to an existing facility which in today's dollars is worth over $150M and not a new start in the conventional sense of the words. When completed the additional operating costs and additional staff will be minimal.

The concept of a Booster Synchrotron injector for the AGS is one that dates back to the mid-1960's. It, however, lay dormant until early 1983, when a small machine design effort was started in the Accelerator Department. This work continued at a low level until the completion of the AGS II Task Force Report (Nov. 1983-Jan. 1984) and its acceptance by the Laboratory Directorate (Feb. 1984). This group of AGS users was organized by the Chairman of the AGS users organization and reported to the BNL Associate Director for High Energy Facilities. As such, the activity involved extended interaction among the user community as well as BNL physicists including several large, well attended, open meetings. With the concurrence of the Laboratory and the BNL high energy physics community, work proceeded at a more deliberate pace resulting in a conceptual design report (May 1984). In May 1984 the BNL plan of a future physics program and accelerator building program was presented to the Department of Energy, Office of Energy Research, Division of High Energy and Nuclear Physics. During the period June 1-5, 1984, an outside technical review was convened and on June 11, 1984, BNL submitted a form Schedule 44 to DOE for construction of the AGS Booster starting in FY 1986. The first of two DOE reviews occurred on June 27, 1984 when a review of the technical details of the proposal was held. The second one, on June 11, 1984, was a cost and validation review by the DOE Office of Project and Facilities Management. Subsequent to this meeting, DOE notified BNL that the Booster was validated in terms of its cost estimate and, therefore, could be a part of the 1986 DOE budget submittal to OMB.

3. (Cont'd)

A formal presentation and discussion on the AGS Booster, including its physics motivation, technical design and costs, was made to HEPAP in June 1984. Subsequently, the project was presented to HEPAP by DOE as part of the high energy program considered for the FY 1986 budget. As a general rule, HEPAP does not make individual recommendations on smaller-scale projects such as this, and, following this procedure, did not single out the project for specific endorsement. However, HEPAP did endorse the FY 1986 high energy physics program plans which did include construction of the AGS Booster. In August of 1984, BNL also made informal presentations to the staff of the OMB and the OSTP. On February 14, 1985, BNL presented its plans, including the Booster, to NSAC. Subsequent to that, Dr. John Schiffer, the present Chairman of NSAC, in his verbal testimony at HST on February 28, 1985, strongly supported the Booster upgrade thereby endorsing the AGS Booster as a logical step in the development of a frontier heavy ion physics capability at BNL.

4. Where would you like Brookhaven to be 10 years from now? What do you see as the important initiatives that Brookhaven should vigorously pursue during this time period?

Brookhaven now plays an important role as a unique source of large experimental facilities, instrumentation, and expertise for high energy and nuclear physics and materials science, and we expect to continue to play a leading role in making the powerful tools and techniques of "big science" available to the scientific community. To this end, I would expect that two projects that have been strongly supported by their respective communities of users: the AGS booster by the high energy community and the HFBR Guide Hall by the materials science community, as indicated by its being at the top of the list of improvements recommended by the Seitz Panel, would be operational by the late 1980's. In addition, in ten years I would also like to see us play a similar role for both basic and applied research in biomedical, chemical and geoscience. To accomplish this, we are planning on expanding the capability of the National Synchrotron Light Source (Phase III) and our Scanning Transmission Electron Microscope. At the same time, I would hope that with the construction of the Relativistic Heavy Ion Collider (RHIC), we will be the premier Laboratory for the study of relativistic heavy ion reactions, the area of science where particle physics, nuclear physics, and astrophysics overlap and where I believe some of the most exciting new discoveries will be made in this century. Again, such a facility has received the highest priority in the NSAC long-range plan.

For the research tools needed in the future, we are in the forefront of R&D into new accelerator techniques such as laser accelerators and improved superconducting magnets. Of course, we expect to be major participants in the SSC and its utilization. Support and organization of these R&D activities is the investment required if we are to make the next 50 years of accelerator-related science as productive as the past 50 years.

Finally, we would like to see Brookhaven further develop its role as a national science resource to government, universities and industry. I would expect our Laboratory to provide a unifying influence among industry and universities for large research projects in the ocean, the atmosphere and in outer space. With our unique history and expertise, I expect that we will continue to evolve optimal and innovative applications of state-of-the-art science and engineering to solve problems of nuclear energy. This means applications to energy generation, waste management, peaceful uses in general, and also to frontier questions of importance to national defense.

5. We sent you a copy of the Committee's Sciency Policy Task Force's Report, An Agenda for a Study of U.S. Science Policy. Would you like to comment on the Report? What important issues concerning the government laboratories in general and your laboratory in particular do you believe should be included in the Task Force's study?

Despite the agreed narrow scope for the Committee's Science Policy Study, the questions posed in the agenda represent a most ambitious and difficult undertaking. During the study, other questions, equally difficult, will undoubtedly arise. As you well know, a number of the questions have been with us for years, and clear, precise answers are often unavailable. In what terms can we measure the strengths and weaknesses of basic research? How are priorities set among the various disciplines in basic research? What is the desirable ratio of basic to applied research? And so on. Two years--a term well understood by the Congress of the United States--will prove a very short time to accomplish the task the Committee has outlined.

You have raised several significant questions concerning the role of the government laboratories in Part II B. Perhaps you should add the extremely important role that users represent in carrying out the research programs at the National Laboratories. At Brookhaven National Laboratory, the largest fraction by far of the research in high energy and nuclear physics, is performed by outside users from the university community or from other laboratories. A similar statement could be made for the programs at the High Flux Beam Reactor, and the National Synchrotron Light Source but in addition at the NSLS, a significant fraction of the research is carried out by industry with a significant monetary contribution from industry.

The following questions could be added to the appropriate areas covered in the Report. The questions posed are only representative--they are not ordered in importance. nor are they intended to be exhaustive:

Are there special advantages that accrue in a multi-program laboratory with a mix not only of scientific disciplines but also of basic and applied research?

What are the benefits to research programs in laboratories where virtually all of the research is unclassified?

Do the national laboratories play an important role in science and engineering education? What quantitative effect do they have on scientific, engineering, and technical manpower?

The national laboratories represent a special resource of talent and equipment that can be utilized by other government agencies for solution of urgent problems. What is the best mechanism for accomplishing such tasks?

D/18.2

BROOKHAVEN NATIONAL LABORATORY

DOE OPERATING BUDGETS
By Appropriation

(In Thousands of Dollars)

BUDGET CATEGORIES	FY 1984 Cost	FY 1985 Current Budget	FY 1986 Budget Before Congress
I. GENERAL SCIENCE AND RESEARCH			
HIGH ENERGY PHYSICS	$ 65,535	$ 62,749	$ 64,500
NUCLEAR PHYSICS	7,297	7,836	10,360
GENERAL SCIENCE AND RES.-TOTAL	$ 72,832	$ 70,585	$ 74,860
II. ENERGY SUPPLY R&D			
NUCLEAR SCIENCES	1,927	2,405	2,275
MATERIALS SCIENCES	22,774	26,528	28,560
CHEMICAL SCIENCES	13,781	14,359	14,190
ADVANCED ENERGY PROJECTS	195	471	0
BIOLOGICAL ENERGY RESEARCH	979	1,110	1,110
APPLIED MATH SCIENCES	664	685	685
SUBTOTAL-BASIC ENERGY SCIENCES	$ 40,320	$ 45,558	$ 46,820
CONVERTER REACTOR SYSTEMS	73	0	0
BREEDER REACTORS	125	0	0
ELECTRIC ENERGY SYSTEMS	1,604	1,700	620
ENERGY STORAGE SYSTEMS	2,541	2,260	1,400*
GEOTHERMAL	566	1,150	0
NUCLEAR FUEL CYCLE	37	0	0
MAGNETIC FUSION	408	250	250
SOLAR ENERGY	910	910	770*
SUBTOTAL-ENERGY SUPPLY TECH.	$ 6,264	$ 6,270	$ 3,040
ENVIRONMENT, SAFETY & HEALTH	1,419	1,400	1,315
BIOLOGICAL & ENVIRONMENTAL RESEARCH	18,273	17,537	14,972
UNIVERSITY RESEARCH SUPPORT	214	500	500
ENERGY RESEARCH ANALYSIS	559	844	750
ENERGY SUPPLY R&D-TOTAL	$ 67,049	$ 72,109	$ 67,397
III. FOSSIL ENERGY R&D			
COAL	1,334	994	625*
PETROLEUM	36	119	0
FOSSIL ENERGY R&D-TOTAL	$ 1,370	$ 1,113	$ 625
IV. ENERGY CONSERVATION			
BUILDINGS & COMMUNITY SYSTEMS	1,613	2,499	1,850*
ENERGY CONSERVATION-TOTAL	$ 1,613	$ 2,499	$ 1,850
V. ATOMIC ENERGY DEFENSE ACTIVITIES			
LOW LEVEL WASTE	350	473	756
MARSHALL ISLANDS	1,724	1,668	1,630
INSPECTION AND EVALUATION	0	0	300*
NUCLEAR MATERIALS SEC. & SAFEGUARDS	1,725	2,275	2,345
MATERIALS PRODUCTION	272	50	0
ATOMIC ENERGY DEFENSE ACTIV.-TOTAL	$ 4,071	$ 4,466	$ 5,031
VI. OTHER APPROPRIATIONS			
GENERAL ADMINISTRATION	0	11	0
INTERNATIONAL POLICY STUDIES	4	26	0
NUCLEAR WASTE FUND	249	1,545	2,340*
ENERGY INFORMATION	829	1,105	690*
EMERGENCY PREPAREDNESS	145	153	0
ECONOMIC REGULATION	41	0	0
POLICY ANALYSIS & SYSTEM STUDIES	103	306	280*
IN-HOUSE ENERGY MANAGEMENT	0	60	0
URANIUM SUPPLY AND ENRICHMENT	16	0	0
OTHER APPROPRIATIONS-TOTAL	$ 1,387	$ 3,206	$ 3,310
LABORATORY TOTAL-DOE	$148,322	$153,978	$153,073

*BNL Estimate

March 1985

D/18.2

BROOKHAVEN NATIONAL LABORATORY
DOE CAPITAL EQUIPMENT BUDGETS
By Appropriation
(In Thousands of Dollars)

BUDGET CATEGORIES	FY 1984	FY 1985 Current Budget	FY 1986 Budget Before Congress
I. GENERAL SCIENCE AND RESEARCH			
HIGH ENERGY PHYSICS	$ 3,400	$ 4,400	$ 4,300
OTHER CAPITAL EQUIPMENT	3,500	3,900	3,900
HIGH ENERGY PHYSICS-TOTAL	$ 6,900	$ 8,300	$ 8,200
NUCLEAR PHYSICS	900	2,745	3,595
GENERAL SCIENCE AND RES.-TOTAL	$ 7,800	$11,045	$11,795
II. ENERGY SUPPLY R&D			
NUCLEAR SCIENCES	50	50	50
MATERIALS SCIENCES	1,415	2,100	2,200
CHEMICAL SCIENCES	1,491	1,302	1,513
ADVANCED ENERGY PROJECTS	138	100	0
BIOLOGICAL ENERGY RESEARCH	100	69	68
APPLIED MATHEMATICAL SCIENCES	50	0	0
SUBTOTAL-BASIC ENERGY SCIENCES	$ 3,244	$ 3,621	$ 3,831
ENERGY STORAGE SYSTEMS	0	35	0
MAGNETIC FUSION	20	20	25
BIOLOGICAL AND ENVIRONMENTAL RESEARCH	914	950	898
ENERGY SUPPLY R&D-TOTAL	$ 4,178	$ 4,626	$ 4,754
III. FOSSIL ENERGY R&D			
COAL	8	0	0
FOSSIL ENERGY R&D-TOTAL	$ 8	$ 0	$ 0
IV. ENERGY CONSERVATION			
BUILDINGS & COMMUNITY SYSTEMS	0	0	300
ENERGY CONSERVATION-TOTAL	$ 0	$ 0	$ 300
V. ATOMIC ENERGY DEFENSE ACTIVITIES			
LOW LEVEL WASTE	50	105	39
MARSHALL ISLANDS	0	40	0
NUCLEAR SAFEGUARDS & SECURITY	28	55	35
ATOMIC ENERGY DEFENSE ACTIV.-TOTAL	$ 78	$ 200	$ 74
VI. NUCLEAR WASTE FUND	13	0	0
NUCLEAR WASTE FUND-TOTAL	$ 13	$ 0	$ 0
LABORATORY TOTAL-DOE	$12,077	$15,871	$16,923

March 1985

D/18.2

BROOKHAVEN NATIONAL LABORATORY
DOE CONSTRUCTION BUDGETS
By Appropriation
(In Thousands of Dollars)

BUDGET CATEGORIES	FY 1984	FY 1985 Current Budget	FY 1986 Budget Before Congress
I. GENERAL SCIENCE AND RESEARCH			
HIGH ENERGY PHYSICS			
ACCELERATOR IMPROVEMENT PROJECTS	$ 2,000	$ 2,000	$ 2,200
GENERAL PLANT PROJECTS	3,200	5,700	5,700
HIGH ENERGY PHYSICS-TOTAL	$ 5,200	$ 7,700	$ 7,900
NUCLEAR PHYSICS			
TANDEM/AGS HEAVY ION TRANSFER LINE	5,000	5,300	0
GENERAL SCIENCE AND RESEARCH-TOTAL	$10,200	$13,000	$ 7,900
II. ENERGY SUPPLY R&D			
BASIC ENERGY SCIENCES			
NSLS-BEAM LINES & SUPPORT AREA	$ 2,500	$ 7,400	$ 7,200
ACCEL. & REACTOR ADD. & MODIFICATIONS	640	1,700	1,795
BASIC ENERGY SCIENCES-TOTAL	$ 3,140	$ 9,100	$ 8,995
MULTIPROGRAM GENERAL PURPOSE FACILITIES			
UTILITY REPLACEMENT & UPGARDE	$ 7,500	$ 3,200	$ 0
FIREHOUSE FACILITY	1,800	0	0
FIRE PROTECTION IMPROVEMENTS	0	0	500
CENTRAL CHILLED WATER FACILITY	0	2,200	7,100
MULTIPROG. GEN. PURPOSE FAC.-TOTAL	$ 9,300	$ 5,400	$ 7,600
IN-HOUSE ENERGY MANAGEMENT			
MODIFICATIONS FOR ENERGY MANAGEMENT	1,220	2,518	2,921*
FUEL STORAGE FACILITY	200	1,000	1,500
COGENERATION FACILITY	0	1,600	10,600
IN-HOUSE ENERGY MANAGEMENT-TOTAL	1,420	5,118	15,021
ENERGY SUPPLY R&D-TOTAL	13,860	19,618	31,616
TOTAL DOE CONSTRUCTION	$24,060	$32,618	$39,516
RECAP			
OPERATING	$148,322	$153,978	$153,073
CAPITAL EQUIPMENT	12,077	15,871	16,923
CONSTRUCTION	24,060	32,618	39,516
TOTAL DOE	$184,459	$202,467	$209,512

*BNL Estimate

March 1985

APPENDIX 1

STATEMENT BY
ENERGY COMMITTEE
OF THE
NATIONAL ASSOCIATION OF STATE UNIVERSITIES & LAND-GRANT COLLEGES

TO

HONORABLE DON FUQUA
CHAIRMAN
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

IN CONJUNCTION WITH
FEBRUARY 28, 1985 HEARING ON
ENERGY RESEARCH

The Energy Committee of the National Association of State Universities and Land-Grant Colleges (NASULGC) is aware of the need for budgetary restraint to reduce the Federal deficit, but it also recognizes the importance of Federal energy R&D programs aimed at developing existing and alternative energy resources by providing the scientific and engineering knowledge necessary to reach the ultimate goal of assuring an adequate supply of available energy at reasonable cost to the citizens of America. University research in fossil energy, in conservation and renewable energy programs, amongst others, is vital to the nation's future, both in the research results themselves leading to technological advances, and in the continued supply of well trained engineers and scientists for industry, government and academic manpower needs.

In working towards these goals, and in consideration of economic, social and defense perspectives, the Committee has determined that:

* University R&D funding for conservation and renewable energy should be increased from 2% ($6.9M) to at least 3% ($10.0M) of the proposed university support budget.

* University R&D funding for fossil energy should be increased from 8% ($26.2M) to at least 10% ($35.0M) (these amounts are exclusive of former university energy centers supported by DOE).

These important R&D areas have suffered several cutbacks in the last few years while other areas have increased significantly. Consequently, a reasonably balanced R&D program no longer exists.

Of particular need are university R&D increases from $3.0M to $4.0M for Energy Conservation Research and $1.7M to $3.7M in Solar Energy Research. The latter should be targeted primarily for solar thermal and biomass R&D. This R&D should provide linkages with the interests of states and regions as well as nationally with industry. Several projects supporting a faculty researcher and one to three graduate students in solar thermal research should be supported. These projects would be in the $100K range, and it is expected that up to 50 universities would respond in this much-needed research program. The DOE FY 1986 Budget Highlights Report states that "Solar and other renewable energy resources offer the potential for significant contributions over the long term." University R&D should be a more significant segment of the investments. The benefits of biomass and solar thermal research are great, but university research in these areas has been reduced to a level which is almost negligible. Increases are critically needed to maintain university capacity and commitment. Continued neglect of biomass and solar thermal will be detrimental in both the short and long term, and the overall contributions of advanced technology development for industrial and defense applications will not be assured.

While the increase to $5.9M in the line item for university coal research (UCR) is a modest move in the right direction, the committee recommends an increase to $8.0M. Current funding provides support for only about 10% of university proposals in UCR, while other Federal energy research areas fund almost half of the unsolicited proposals received. Opportunities for young faculty in coal engineering and science are limited, and the recommended increase should attract bright, creative minds with new and advanced concepts for research projects. Research initiation grants for young faculty in coal engineering and science should be commenced to maintain the vitality of the research/manpower development process. Direct and indirect liquifaction research are both critical in the long-term search for better conversion processes, and there is new promise for enhanced oil recovery.

It is reasonably clear that state and private sector investment could not support the level of research which is needed in coal, biomass, and solar thermal energy to achieve progress in the interest of a national, balanced, and sound energy R&D policy.

The increases recommended for university R&D will provide a better balanced program without undue effects on other areas of the proposed DOE budget, and will assist in retaining the universities capacity to actively cooperative and assist in the attainment of national energy goals.

The NASULGC Energy Committee shares Secretary Harrington's strategy in applying emphasis on the most essential longer-term research and development, leaving short-term engineering development and commercial application wherever possible to the private sector. The Committee would further stress that investment in human capital is no less important to the economy than machines and industrial plants and that the advance of energy science in its broadest sense is a significant factor in the growth and productivity of the United States.

Thank you for the opportunity to present this statement.

APPENDIX 2

ADDITIONAL MATERIALS FOR THE RECORD

DOE/ER-0212

December 1984

Materials Sciences Division Long Range Plan

U.S. Department of Energy
Office of Energy Research
Office of Basic Energy Sciences
Washington, D.C. 20545

Materials Sciences Division

Office of Basic Energy Sciences/Energy Research
U.S. Department of Energy

LONG RANGE PLAN

A vision of the future over the next decade
incorporating new opportunities and
continuing the commitment to excellence.

December 1984

Table of Contents

Page

PREFACE.. 3

EXECUTIVE SUMMARY...................................... 4

INTRODUCTION... 8

RESEARCH...10

- Metallurgy and Ceramics..........................11
- Solid State Physics..............................13
- Materials Chemistry..............................14

CENTERS FOR COLLABORATIVE RESEARCH....................17

- Neutron Sources..................................18
- Synchrotron Radiation Sources....................19
- Electron Microscopy..............................20
- Center for Advanced Materials....................21

RECENT PROGRESS AND ACCOMPLISHMENTS...................23

CONSULTATION, REVIEW, AND COORDINATION................29

- Consultation and Review..........................29
- Coordination.....................................31

TECHNOLOGY AND INFORMATION TRANSFER...................32

FUNDING REQUIREMENTS..................................35

APPENDIX..41

PREFACE

The intent of this document is to provide a framework for programmatic guidance into the future for Materials Sciences. The Materials Sciences program is the basic research program for materials in the Department of Energy. It includes a wide variety of activities associated with the sciences related to materials. It also includes the support for developing, constructing, and operating major facilities which are used extensively but not exclusively by the materials sciences. Other materials programs of the Department, which concentrate on the more applied or energy technology oriented end of the R&D spectrum, are coordinated as appropriate with the Materials Sciences program primarily through the internal DOE committee, the Energy Materials Coordinating Committee. The disciplines of solid state physics, metallurgy, ceramics, and materials chemistry are used in the program to explore and create the underpinnings for future materials development important to the Nation's energy program.

Research is aimed at either providing solutions to outstanding materials problem areas or creating new materials opportunities which would provide the materials basis for entirely new approaches to the design of energy systems. Synthesis, preparation, and processing of existing or new materials is one of two major thrusts within the program. The other major thrust is the characterization, including property measurement, of materials. The decade ahead will show advances in both; sometimes opportunities will be more readily available in one rather than the other. The instrumentation and facilities needed to pursue these opportunities or which in fact provide these opportunities are an essential part of the research activities. By displaying this comprehensive plan, reactions from the research community can be put into context; and the program plan modified appropriately.

This document should be considered only the first in a series of plans. It will be reviewed and revised periodically as new information and new national policies alter its content. The overall constraint of funding will tend to shift certain activities from year to year, as is already evident between the time of document preparation (August 1984) and the time of publication (December 1984). This document should be considered a snapshot as of August 1984. Nevertheless, the important point to be made with this document is the establishment of a strong foundation upon which future program directions can be debated, justified and supported. The report was prepared by the Materials Sciences Division staff and has had a preliminary review by the Division's Council on Materials Science and by the DOE laboratories. Special acknowledgment is due to Dr. Iran Thomas of the Materials Sciences staff who coordinated and prepared much of the material in the report and Mrs. Sandra Tucker who typed the manuscript.

Louis C. Ianniello, Director
Division of Materials Sciences

EXECUTIVE SUMMARY

This long-range plan provides a framework for programmatic guidance into the future for the Division of Materials Sciences of the Office of Basic Energy Sciences, U.S. Department of Energy. General research areas of interest are discussed and the major facilities needed are described. Examples of recent accomplishments are given to demonstrate the importance of the program. Review of the program through consultation with the scientific community and coordination with other Federal programs is described. The efforts to increase technology and information transfer to U.S. industry are discussed and the funding projections for the Materials Science program are given.

Materials, with better and predictable properties, which can be used with confidence in harsh environments and under extreme conditions, are needed now to support existing energy technologies and will provide new opportunities for energy technologies of the future. The research plans are included within two major areas for future emphasis. One is advanced synthesis, preparation, and processing of existing or new materials; and the other is specialized characterization and measurement of properties of materials.

The selection of research to be emphasized during this planning period is based on a large number of studies. The reports of these studies are listed in the Appendix. Because of limited resources, only the more promising and exciting topics have been selected. Research in metallurgy during the coming decade will focus especially on interface and surface phenomena, non-equilibrium phenomena, and materials reliability and lifetime prediction. In ceramics the goal includes ceramic materials that have homogeneous, flaw-free microstructures with high fracture toughness. Research will be conducted to develop reliable and predictable processing methods, on ceramic composite materials, and on ceramics with novel properties. Analytical electron microscopy is extremely important in the study of materials; however, current resolution is limited to about 10 nm. This resolution will be improved to about 1 nm which will allow analysis of microstructural features containing less than 100 atoms, such as are found in interfaces. Knowledge of composition of these microstructures is needed to predict bulk properties. Other advances in electron microscopy will allow the study of dynamic phenomena such as fracture or oxidation. In Solid State Physics, research during the next decade will continue to focus on the fundamental understanding of the physical properties of materials. Physical properties of materials will be correlated with detailed spectroscopic and microscopic features. More complex classes of materials, such as multi-element single crystals, amorphous materials, layered and coated materials will be emphasized. These efforts will provide the basis for advanced superconducting, semiconducting, magnetic, corrosion resistant, ultrahard, and ultrastrong materials. Theoretical understanding of complex material phenomena will advance significantly with access to supercomputers. Advanced major facilities such as synchrotron radiation sources, neutron sources, and electron microscopes will be used to study the structure and properties of materials not possible previously.

These advanced facilities will provide knowledge about organic, metal compound, composite, polymeric, and amorphous materials needed to design new materials. The dynamics of structural transformations, fatigue, and other time dependent phenomena will be studied using pulsed sources. Research using synchrotron radiation will advance X-ray microlithography; significantly leading to the next generation of integrated circuits. The focus in Materials Chemistry will be on experimental and theoretical research in chemistry leading to new and improved materials and describing the chemical structure and properties of materials. Synthesis efforts will focus on novel catalytic materials, organic conductors, polymers, and ceramic precursors. In surface chemistry the emphasis will be on the understanding of the interfacial chemical reactions on surfaces exposed to solutions and gases and on surface coatings to protect or modify surface properties of bulk materials.

During the last two or more decades, there has been a growing need for major centers with unique equipment at which materials scientists can perform specialized types of research. These centers offer the most effective way to make very expensive equipment accessible to all qualified scientists as well as ensuring the proper maintenance of the equipment. Recently, the need for major facilities was reviewed by the National Research Council. Their conclusion was "that both new facilities and new capabilities at existing facilities are essential for the effective evolution of science and advanced technology in the United States in the next decade and beyond."[1] The Division of Materials Sciences supports wholly or in part 15 centers. There are three major facility construction projects that are underway already and will be completed during this planning period. These are the Phase II of the National Synchrotron Light Source, the enhancement of capabilities at the Stanford Synchrotron Radiation Laboratory, and the Center for Advanced Materials. Several major new facilities have been recommended by the scientific community. Priorities for these facilities have not yet been set by DOE; however, the NRC Major Materials Facilities Committee recommended the following priorities: (1) a 6 GeV synchrotron radiation facility, (2) an advanced steady state neutron facility, (3) a 1 to 2 GeV synchrotron radiation facility, and (4) a high intensity pulsed neutron facility. Among these, plans for the 1 to 2 GeV are more advanced since a proposal for this facility has been received and reviewed. Proposals for the 6 GeV facility are in preparation. The steady state neutron facility is in an early stage of planning. The advanced pulsed neutron source will not be considered pending results from the high flux pulsed neutron source at Los Alamos. The recommended enhanced capabilities at existing facilities, BNL-HFBR and LANL-PSR/SNR have been reviewed and are ready to be constructed as soon as funds become available.

The research program of the Division of Materials Sciences is large, varied, and active. During the last five years there have been many notable accomplishments in the development of new techniques and facilities for the preparation, characterization, and analysis of materials, the understanding of materials phenomena and properties, and the discovery of new materials. For example, research has shown that in irradiated alloys, alloying elements can segregate and convert the homogeneous alloy into a heterogeneous material where helium atoms form lattice defects and nucleate gas bubbles. These effects are important both fusion and fission reactors. Research in photocells has led to multi-band gap cells of much higher efficiency than single band gap cells. For example, a two-band gap cell had an efficiency of 28.5 percent compared with the 15 percent efficiencies found in most single gap cells. In the area of mechanical behavior and corrosion, constitutive equations have been developed that help pinpoint the mechanism of premature failure of fuel pin cladding in nuclear reactors. For pressure vessels containing hydrogen, such as those used in petrochemical plants and in coal liquefaction, a model was developed that describes the physical mechanism for methane bubble formation in steels and shows that the bubbles can be removed by proper heat treatment. Stress corrosion cracking studies have shown that fission product iodine is not the cause of cracking in zircaloy because it is chemically bound by cesium as cesium iodide and that fission product cadmium is the more likely candidate. Theoretical research has improved our ability to predict the electronic band structure and structural properties of semiconductors. Research in ceramic materials yielded a method to prevent agglomeration of colloidal-sized silicon nitride powder. It is necessary to prevent agglomeration to obtain reliable, sintered silicon nitride components for high-temperature, high-strength applications. Research in amorphous metals has shown that metallic glasses can be prepared at low temperatures by directly reacting crystalline materials with certain rapidly diffusing species. This discovery may allow the preparation of bulk metallic glasses. Metallic glasses are interesting because they have properties that are superior to ordinary metals in many applications, but their use has been limited because previously the method of preparation was costly and yielded only thin ribbons. A new class of dual phase steel alloys having greater strength and fracture resistance has been developed. These steels can be fabricated using current commercial methods, and could lead to an annual energy savings through weight reduction of about 10 percent in the transportation sector. Research on the synthesis of ceramic materials has produced wear resistant coatings of titanium diboride and high-temperature solar energy absorbing films of zirconium diboride. Complex ceramic coatings have been made that have a controlled chemical composition, graded from metallic to ceramic at the outer edge, which can withstand severe thermal cycling. There have also been significant developments in instrumentation. Superconducting quantum interference devices are being used to detect movement at geological fault lines for earthquake prediction and for geothermal exploration and oil production. Small angle neutron and X-ray scattering have been used to measure the size, shape, and pore distribution of oil in oil shale, nondestructively. Neutron time of flight techniques have been used to measure residual stresses in materials. A portable infrared detection instrument was developed that made possible rapid, real-time airborne studies of stack gas plumes from coal fired steam plants which will lead to a better understanding of acid rain.

The Division of Materials Sciences seeks information from many sources to help define the program. For research specific to the Division, information is sought from the Council on Materials Science, special workshops, peer reviews of unsolicited proposals, DOE Laboratory research proposals, and DOE

Laboratory information meetings. The Energy Research Advisory Board deals with issues involving all of the Department of Energy and many of their recommendations are pertinent to the Division of Materials Sciences. The National Research Council, OSTP, and OTA deal with even broader issues but often their recommendations affect the Division and its relations with other agencies in the Federal government.

Coordination of the program within the Department is done primarily through the Energy Materials Coordinating Committee which meets bimonthly. At the Federal agency level several formal coordinating committees exist such as the Interagency Committee on Materials, and the OSTP Committee on Materials.

In the 36 years that the Division of Materials Sciences has been in existence, it has been an effective contributor to technology used by industry. For example, the separation processes for samarium used in samarium cobalt magnets, rare earth elements used for phosphors in television sets, and zirconium used in nuclear fuel cladding were discovered in programs supported by the Division. Other discoveries used by industry are the He^3-He^4 dilution refrigerator now marketed world wide, metallic glasses that are being developed for low loss cores in electrical transformers, a method for synthesizing organic superconducting materials, superconducting quantum interference devices that are used by many companies in geophysical exploration, and an improved process for the production of glass-reinforced, polymeric dental filling material.

The students who receive advanced degrees under support from the Division are as important as these direct technology transfers. In 1983, about 180 new scientists trained in materials sciences related disciplines entered the work force. The knowledge gained and reported in the scientific literature (over 8,000 articles during the last five years) make the results of the research sponsored by the Division accessible to scientists in industry, universities, and government. In addition, industry is making use of the advanced facilities supported by the Division. At NSLS, for example, industrial investment exceeds 5 million dollars and 14 percent (and growing) of the 1983 users of the Centers for Collaborative Research were industrial scientists. The plans are to increase our efforts at technology transfer. The involvement of industrial scientists will be increased in panels, workshops, and other meetings. The Center for Advanced Materials has been initiated from the beginning with the intent to have industrial participation, and industrial participation will be encouraged at all the National Laboratories.

The funding requirements for the long range program incorporates overall growth in the core research program which supports scientists engaged in forefront materials research, a more substantial growth in the support for the operation of major user or collaborative research centers, and a commitment to a construction program providing major new, forefront instruments and facilities. The overall real growth for the total program is projected at 6 percent per year.

INTRODUCTION

The science of materials has reached a point where many believe it is now possible to achieve significantly larger advances in understanding materials behavior and to develop highly advanced, more improved materials. This is the result of the present high level of understanding, the increasingly wide range of experimental and theoretical techniques available, and the large and growing computational capability offered by modern high speed computers. At all levels of the Federal government including the Congress, interest in the field is high. In basic materials research, the Federal government spends about $0.4 billion per year spread among several agencies, but especially DOE, NSF, and DOD. To put this sum in perspective, the total annual Federal funding of materials research and development is about $1 billion; and the annual funding from industry, mostly on applied research, is about $4 billion.

The need and benefits of materials research are very evident. In the field of energy, almost all systems for energy production, conversion, or transportation suffer from materials problems or would benefit from improved materials performance. Also, materials technology clearly plays a crucial role in developing new high technology industries. Each new advance in materials performance opens up the possibility of better engineering systems or entirely new industries.

For energy systems, there are many outstanding problem areas related to materials. Fission reactor technology faces materials challenges from nuclear waste containment, fuel cladding integrity, and control of stress corrosion cracking. In fossil energy systems, high temperature corrosion due to sulfur and other minor impurities is a constant difficulty for coal conversion plants. Catalysts are extremely important for fuel productivity. Better understanding of their mechanistic role and deterioration would lead to plant improvements. Although the promise of solar energy is substantial, real use is limited primarily by the cost, performance, and lifetime of materials involved in the conversion process. Photovoltaic materials still convert only a small fraction of the solar energy to electricity. Mirror materials for reflecting solar energy degrade easily under the effect of both thermal cycling and environmental reactions. For energy storage, advanced high temperature batteries are very dependent on progress achieved in reducing the corrosion of electrode materials at high temperatures. For vehicle propulsion, ceramic components could provide a substantial improvement in fuel efficiency and the ability to use lower cost fuels. However, structural ceramic engine components would have to be made reliably and flaw free. For fusion energy, once feasibility has been established, materials concerns will dominate the engineering of reliable systems. For example, materials for superconducting magnetic systems will greatly affect plant capital costs; and the radiation response of structural materials will affect plant lifetimes. These are just a few examples of how materials problems limit or determine the operational characteristics of energy systems.

On the other hand, opportunities opened by advances in the science of materials often can lead to entirely new applications of materials. Major advances are being made in the preparation of materials with tailored properties. For example, the surfaces of steels can be modified by ion implantation to change the friction and wear properties; layered materials can be prepared on an atomic scale; and experimental probes are available to examine the electronic, atomic, magnetic, defect, and micro-structure of materials. Recently, unprecedented advances have been made in the development of these probes using laser sources, synchrotron radiation sources, neutron sources, and high resolution electron microscopes. Advanced high speed computer capabilities coupled with theory and physically based models have allowed significant new progress in our understanding of old problems such as phase transformations, defect structures and hydrogen effects.

Materials research is both a mature research field and an exciting nascent scientific frontier. Significant background must be considered when investigating the mature sub-field of steel materials. Nascent areas such as organic superconducting materials or ion implantation, on the other hand, do not have an extensive research history. To investigate new, forefront topics regardless of the state of maturity of the area, materials research will require the interaction among many disciplines. Materials research will also require experimental facilities as simple as an optical microscope or as complex as nuclear reactors and synchrotron radiation sources. It is essential to maintain a strong national capability in all these areas to meet the energy and defense objectives of the Department of Energy, to have a strong scientific base with which generic solutions to technical problems may be found, and to exploit discoveries wherever they are made. The challenge for the next decade will be to investigate the difficult areas of more complex phenomena, to tailor materials properties, and to gain understanding of outstanding theoretical and experimental issues with the new techniques and approaches. The promise of success is so great that not to attempt will only probably leave us far behind in the technological race.

10

RESEARCH

The Division of Materials Sciences traces its origin back to the Atomic Energy Commission's metallurgy and materials program of 1948. The Division of Materials Sciences has been responsible for many significant discoveries and developments during its 36 year existence, notably: neutron scattering, which has greatly aided our modern understanding of materials; separation, preparation, and property measurements of individual rare earth elements which are used in lasers and as phosphors in television sets and computer display monitors; amorphous metals which have started new areas of research and technology; and laser annealing combined with ion implantation which is now used routinely by the semiconductor industry. The overriding accomplishment has been the establishment and maintenance of a materials science effort of the highest quality which can be and is being used by the entire nation's technical community. This has been achieved through the appropriate support of forefront materials sciences research in national laboratories, universities, and industry. The Division of Materials Sciences has directly supported scientists carrying out the research and constructed and operated major facilities necessary for the conduct of materials research by scientists and engineers throughout the nation.

Over the past 5 years, significant progress and accomplishments have been achieved in the areas of: (a) development of new techniques and facilities for preparation, characterization and analysis of materials, (b) understanding of materials phenomena and properties underlying known energy-related problem areas, and (c) discovery of new materials and phenomena which may open new energy-related opportunities for future systems. Examples of these accomplishments are discussed under Recent Progress and Accomplishments, page 23.

The primary purpose of the Materials Sciences subprogram is to increase the understanding of materials phenomena and properties important for energy related materials development efforts and thereby provide new materials related options in the long term. As a measure of the knowledge gained, the scientific and technical literature contained over 8,000 publications produced by this program during the last 5 years. In this same time span over 650 new scientists and engineers familiar with energy materials research have been trained. They are an important national resource.

The Materials Research is organized in three major categories. These are: Metallurgy and Ceramics, Solid State Physics, and Materials Chemistry. In the metallurgy and ceramics category, research is conducted on the structure of materials, mechanical properties, physical properties, radiation effects and engineering materials by materials scientists, metallurgists, and ceramists. The principal aims are to understand the relationship between the structure and properties of materials and to understand processing influences and the phenomena that govern the defect, atomic, and microstructure of materials. In this category, researchers study for example, the microstructure of dual phase steels, fatigue properties of alloys, oxygen diffusion in ceramic oxides, ion irradiation induced swelling of materials, and the effect of welding parameters on weld structure and properties.

In the solid state physics category, solid state physicists study the fundamental properties and theory of the condensed state of matter in the areas of neutron scattering, experimental and theoretical solid state physics, particle-solid interactions, and engineering physics. For example, researchers in this category study the magnetic structure of rare earth compounds using neutron beams; the modification of surfaces by ion implantation and laser annealing; the electronic structure of surface atom layers in elemental catalysts using synchrotron radiation; the theoretical simulation of crystal defects; ion backscattering to understand the fundamental solidification process; and the use of superconducting devices to map very weak magnetic fields.

In the materials chemistry category, chemical synthesis and structure, high temperature and surface chemistry, and polymers and engineering chemistry are studied by materials chemists. The objective is to understand the chemical aspects of materials. Researchers in this category study, for example, chemical structure of one-dimensional organic conductors, chemical composition of surfaces, and molecular structure using X-ray and neutron crystallography.

Research plans for the coming decade for each of the categories are given in the next three sections. Necessarily these plans are focused on a few topics and are based on the state-of-knowledge today. Of the many deserving topics, only a few carefully selected ones are highlighted. They are of such importance and complexity that it may take a decade to achieve results and have a significant impact on science or technology and affect the nation's energy plan.

Metallurgy and Ceramics

In metallurgy, the focus will be in three broad areas--interface and surface phenomena, non-equilibrium phenomena, and materials reliability and lifetime prediction.

Work on interfaces and surface phenomena is important because of the great influence surfaces, both external and internal, have on controlling the physical and chemical behavior of materials. Most materials are used in a polycrystalline state and the interfaces between the individual crystallites or grains have a large effect on the bulk properties of the material. The external surfaces of materials may have chemical compositions and structures that differ substantially from the bulk. Research will be done on the structure of interfaces; the interaction of external surfaces with gases, aqueous solutions, and molten salts; the defect structures and interfacial stability under various external environments (temperature, pressure, radiation, gaseous composition); cooperative phenomena such as the interactions between impurities and structural defects for moving interfaces, nucleation, and crystal growth, and grain boundary movement and growth; and strained layer superlattices.

Non-equilibrium phenomena are important because synthesis and processing of materials often depend on transient, non-equilibrium states. Mechanical failure is a non-equilibrium phenomenon, as well. These phenomena are more complex and not as well understood as equilibrium phenomena. In materials synthesis, work will concentrate on the formation of new materials, on the atomistic characterization of interfaces between growing phases, on modelling fluctuations at interfaces, and on cooperative phenomena such as those associated with phase transformations and defect diffusion. We also plan to develop probes to study non-equilibrium phenomena as they occur using, for example, intense neutron and X-ray sources and acoustic emission. Novel materials, such as amorphous metals, modulated or layered materials, and intermetallic electronic compounds will require additional research in order to understand better their behavior.

Under deformation and fracture, our interest will be in triggering mechanisms involved in dynamic recovery and hardening processes, cooperative effects in deformation or shear localization and crack initiation, and physically-based, mathematical micromechanical models. Under corrosion and electrochemical phenomena, research will be on the critical events leading to destabilization of the protective surfaces and films, on large scale surface corrosion and small scale pitting, and on the physical basis of incubation times to breakaway corrosion.

Few areas in materials are more important than reliability and life prediction. In traditional materials such as structural alloys, research will focus on the correlation of local structures such as grain boundaries, weldments and surfaces, with bulk properties. A firm understanding of failure processes and methods to detect and predict incipient failure will be sought.

Because of their growing importance, ceramics as a class of materials will be emphasized. Ceramics are attractive because they can withstand high temperatures and harsh chemical environments and they can be made from abundant elements, but they suffer from intrinsic lack of toughness. Our goals are: to synthesize ceramic materials that have homogeneous, flaw-free microstructures, and novel properties; to develop reliable and reproducible synthesis and processing methods; and to understand the behavior of ceramics especially with regard to fracture toughness. Research will be done on materials such as whisker and fiber reinforced composites, spinodal systems, glass-ceramic materials, and non-equilibrium, metal-ceramics including those prepared by rapid solidification. Low temperature ceramics such as cements, and superconducting ceramics such as ternary molybdenum sulfide will also be studied. The synthesis methods to make powders that will receive attention include chemical vapor deposition, sol-gel, plasma, laser, and combustion methods. The methods for processing the powders into ceramic bodies will include hot pressing, hot isostatic pressing, and high-pressure, hot pressing. Considerable emphasis will be placed on the synergistic relationship between process parameters and microstructure and properties and behavior.

Solid State Physics

In solid state physics, research during the next decade will continue to focus on a fundamental understanding of the physical properties of materials, which can be obtained only through a strong interactive experimental and theoretical research effort. This understanding is not only scientifically interesting, it is essential for the ultimate prediction and development of new materials with desired technological properties. While the important physical properties of materials will be correlated with detailed spectroscopic and structural features, special emphasis will be given to promising developments in the preparation and characterization of totally new materials. Solid state physics has usually led the way in the development of powerful and new techniques for the study of matter and we anticipate that it will continue to do so.

In materials preparation, new levels of purity and perfection will be achieved in classes of tailored materials synthesized by a variety of methods. The steady advances in materials synthesis will be accomplished through the increased use of "smart systems" able to modify rapidly the preparation parameters, controlled by models incorporated into high-speed computers. Friendly access to supercomputers will permit theoretical probing of complex material behavior that has hitherto been unattainable. It will also expand new theoretical calculations in the predictive mode to assist advanced materials design. On the smaller scale, computer linkages at major facility experiments will grow in sophistication and efficiency. Tailoring of materials will be accomplished by modification with ions and lasers. The various advanced synthesis systems will be joined by "on-line" instrumentation to permit property measurements and allow for real-time synthesis modifications. The types of materials under study will extend from dislocation-free, pure, single crystals, to amorphous structures, unusual layered and coated materials and multiphase, multielement complex materials. The uses of static and dynamic pressures to new high levels will be used to create materials exhibiting new phenomena. Again, to the extent possible real-time dynamic analysis will be employed. It is expected that ion source fluxes will be improved by an order of magnitude thus making these sources useful for the large scale ion implanting of large surfaces for applied uses. Laser and plasma assisted processing will be exploited. Advanced semiconducting, superconducting, corrosion resistant, magnetic, and ultrastrong, ultrahard materials will be created.

It is expected that instrumentation for the characterization and property measurement of materials will continue to outpace the development of the advanced synthesis systems. The use of advanced major facilities such as synchrotron and neutron sources (both steady-state and pulsed) with increased fluxes will be exploited to bring new knowledge about solids and liquids on the most fundamental level. In the case of pulsed sources, dynamic phenomena such as fatigue will be investigated. The high intensities will provide new information about organic, compound, polymeric, and amorphous materials that will aid the design of new materials. The behavior of materials under extreme environments will be emphasized. X-ray microscopy and holography will be advanced as will the use of synchrotron radiation for microlithography. Intense beams of infra-red radiation will be available from synchrotron radiation sources with fluxes several orders of magnitude higher than used now. These sources will open new areas of infra red spectroscopy of condensed matter.

Materials Chemistry

In materials chemistry, the emphasis in the coming decade will be on theoretical and experimental research in chemistry and chemical physics leading to new and improved materials and understanding of the chemical structure and properties of materials.

Synthetic chemistry is an especially promising area. During the last decade, there have been exciting discoveries, such as organic conductors and superconductors; and synthesis methods have advanced to achieve a remarkable degree of control. Our plans are to synthesize and understand organic and polymeric conductors. The chemistry of organic materials with magnetic properties, macromolecular materials, and fast ion conducting glasses, ceramics, and polymers will also be explored. By the end of the decade, we expect to understand these materials well enough so that they can be used to replace metals in suitable applications where their light weight and other properties are needed--e.g., batteries for automobiles. In catalysis, our plans focus on novel catalytic materials. Natural enzymes are highly selective catalysts, but they are extremely complex, large molecules that are very sensitive to heat and other chemical variables. Our understanding of the structure of enzymes and synthesis is at the stage that we can begin to synthesize of molecules that mimic enzymes (but do not have their biological complexity) and are tailored to catalyze reactions leading to very specific products. Also we plan to continue research on the synthesis of zeolites so that specific and predictable structures can be made reliably. Zeolites are important because they can be made with particularly shaped micro cavities and channels. Selective catalysts can then be made from zeolites allowing only certain sized molecules to diffuse in or out. Another class of catalysts, intermetallic compounds, are also of interest because they have shown novel catalytic properties that differ from those of their constituent elements.

Considerable progress has been made in synthesizing and controlling microstructures on surfaces. For example, titanium electrodes coated with ruthenium and titanium oxides are much more efficient than carbon electrodes for the production of chlorine. The oxide layer serves as an electrocatalyst and also protects the titanium. There have been interesting experiments with other coatings. For example, polymer coatings have been used to anchor redox centers; electroactive groups have been attached to electrode surfaces using silane reagents; and electrodes have been coated with conducting polymers and layered structures. We plan research on electrode surface and electrocatalysis that could lead to more efficient photoconversion, storage of solar energy, fuel cells, batteries, and electrochemical synthesis.

Materials, such as polymers and inorganic solids, are important in structural applications. In polymers, our interests are in high-strength, heat stable polymers and composites. In ceramics, we are interested in: inorganic and organic compounds as precursors to ceramics; chemical methods for making fine powders, and in the chemical reactions occurring during consolidation or sintering of powders. We plan to undertake research in the chemical properties of these materials (including solid state chemistry and structural chemistry) and in the correlaton of these properties with bulk structure and stability so that new materials can be designed with predictable properties. Research is also planned in chemical reactivity and reaction pathways so that synthesis methods can be developed.

Research in surface chemistry will continue to be emphasized. During the last decade, there has been impressive progress in our understanding of surfaces in a vacuum. In the coming decade, we plan to give special attention to research in surface chemistry at the solid-liquid and solid-gas interfaces and to surface coatings that protect or modify the surface properties of the base material. We also plan research in the chemical aspects of non-linear, non-equilibrium, and critical phenomena because such phenomena are not understood well and often materials are used or made under non-equilibrium conditions.

CENTERS FOR COLLABORATIVE RESEARCH

The Division of Materials Sciences supports either wholly or in part, fifteen Centers for Collaborative Research. These Centers are: High Flux Beam Reactor at Brookhaven National Laboratory, Neutron Scattering at the High Flux Isotope Reactor at Oak Ridge National Laboratory, Intense Pulsed Neutron Source at Argonne National Laboratory, Spallation Neutron Research/Proton Storage Ring at Los Alamos National Laboratory, National Synchrotron Light Source at Brookhaven National Laboratory, Center for Microanalysis of Materials at the University of Illinois at Urbana-Champaign, Materials Preparation Center at Ames Laboratory, Electron Microscopy Center for Materials Research Facility at Argonne National Laboratory, National Center for Electron Microscopy at Lawrence Berkeley Laboratory, Shared Research Equipment Program at Oak Ridge National Laboratory, Surface Modification and Characterization Collaborative Research Center at Oak Ridge National Laboratory, Combustion Research Facility-Materials Program at Sandia National Laboratories/Livermore, National Center for Small Angle Scattering Research at Oak Ridge National Laboratory, Low Temperature Neutron Irradiation Facility at Oak Ridge National Laboratory, and the Stanford Synchrotron Radiation Laboratory at Stanford University.

The primary reason for the existence of these Centers has been the needs of the Department of Energy and its predecessor agencies. However, through the years the value of these Centers to the general scientific community has become evident as collaborations with scientists at the host laboratories increased. This growing need for major centers at which materials scientists and others can perform particular, specialized types of research has been a clearly defined trend covering two or more decades. These Centers offer the most effective way to make extremely expensive equipment accessible to all qualified scientists as well as ensuring the proper maintenance of the equipment. Furthermore, the Department of Energy benefits because users contribute different viewpoints and ideas extending and complementing the research of the Department.

Scientists from universities, industries, and government laboratories can use these facilities subject to the review procedures adopted by each center. Activities that can be done at commercially available laboratories are not appropriate for these centers. There are no charges for research that is not proprietary and is published in the open literature. Proprietary research may be done, but the full cost to use the facility is charged to the user. A brief description of each of these centers is given in reference 9.

Large facilities, such as neutron and synchrotron light sources, require careful planning to construct and operate. Typically, these large facilities take a decade to complete. The process begins with a definition of the scientific needs that cannot be satisfied by existing facilities. At various stages, workshops and panels are convened to determine the characteristics of the facility and to give advice on the design. For example, during 1984, there were two National Academy panels[1, 2] and two DOE/DMS panels[3, 4] on large facilities, There were several workshops held in 1983 and 1984 on the research program of the Center for Advanced Materials[5], under construction.

As we plan for these large facilities, special attention must be paid to the portion of the materials research program that is not dependent on large facilities. Important questions are often answered with simple equipment and a sharp mind (our most important and versatile instrument). There are several safeguards that ensure that facility operations do not have an adverse effect on the non-facility part of the program. Most of the consultation and review regarding programmatic content and direction deals with non facility research (see Consultation, Review, and Coordination, page 29); therefore, the non-facility research is extensively represented in the process that defines the program. Many of the Centers for Collaborative Research were organized to provide access to advanced instruments to researchers unconnected to large facilities. These Centers have several instruments. By placing all these instruments in a center, overall costs are reduced because fewer maintenance people are needed and usage factors are increased. Also, the productivity of the research is likely to increase because the center will be staffed with scientists who are experts in the use of the instruments, and they can advise users who are usually not experts. Examples of these centers are the National Center for Electron Microscopy, the Electron Microscopy Center for Materials Research, Shared Research Equipment Program, the Center for Microanalysis of Materials, the Surface Modification and Characterization Collaborative Research Center, the Materials Preparation Center.

Many of the research facilities cannot be built or operated on a small scale. Neutrons require fission reactors or accelerators and major synchrotron sources require large accelerator systems. The Department of Energy has the expertise to build and operate these facilities and require such facilities to carry out its mission. Research related to nuclear and fusion energy require advanced knowledge of the structure and behavior of materials much of which cannot be obtained without these facilities. It is also clear that these large facilities are extremely valuable and, in providing information that cannot be obtained in any other way for many scientific and engineering disciplines. Advances in science and technology in many areas depend more and more on the availability of these large facilities. Between 1978 and 1983, the number of users of the neutron scattering facilities more than doubled; and the non-traditional users such as biologists and polymer chemists increased by 2 1/2 times.[2] A recent survey showed that the Centers had about 900 users during a 1 year period--21 percent from DOE laboratories, 48 percent from universities, 14 percent from industries, and 17 percent other. Our plans for the next decade take into consideration this increasing demand. The plans and status of neutron sources, synchrotron radiation, and the Center for Advanced Materials are discussed in the following sections.

Neutron Sources

Present: Neutron scattering research has been indispensable to the fields of magnetism, phase transitions, superconductivity, crystallography, and polymer chemistry, just to name a few examples. Neutrons have also been indispensable in neutron activation analysis, production of radio isotopes and pharmaceuticals, neutron radiography, and other applied areas. We are entering a new era where neutrons are being used in more complex and interdisciplinary problems such as studies of residual stresses in metals and ceramics, diffusion of hydrogen in materials and complex biological molecules, hydrogen embrittlement, and materials characterization in general.

Future: To satisfy the needs of the growing users-community of scientists that need to use neutrons in their research, it is necessary to expand the number of available neutron beam lines at the DOE reactors (HFBR and HFIR) and pulsed sources (IPNS and SNR/PSR). Older, less-efficient instrumentation will be replaced so that, during the coming decade, there will be a progressive improvement in instrumentation and detector configurations.

At HFBR at Brookhaven, a neutron guide hall will be added which will permit thermal and cold neutron beams to be guided into a large experimental room. A total of 10 additional instruments could be accommodated in this area. Instruments that will be added to HFBR that are not now available at DOE reactors include the spin-echo polarized neutron spectrometer, a back scattering spectrometer for measuring quasi-elastic neutron scattering, and a high resolution multi-detector powder diffractometer.

Construction of a new reactor could begin during the latter half of the planning period. The cost is estimated to be $260 million (FY 1985 dollars), and construction would take 6 years. A new reactor is needed because of the need for higher neutron fluxes and because the existing reactors were built in the 1960's and will towards the end of the century reach the end of their useful life.

This new steady state neutron facility would have fluxes five to ten times higher than existing reactors. Experiments that require higher fluxes include scattering of polarized neutrons, surface studies with cold neutrons, small angle neutron scattering to study the microstructure of materials, and molecular interactions in polymers.

Spallation neutron sources have only in the last couple of years become important materials sciences facilities. Recent scientific and technological advances at these sources, particularly at the IPNS at Argonne, indicate clearly that further development of these sources should be pursued. At the Los Alamos SNR/PSR pulsed source an additional experimental hall will be added to permit a greater variety of instruments to be used in order to exploit the unique capabilities of the higher energy pulsed neutron beams with time-of-flight instrumentation. Typical experiments include studies of high energy molecular vibrations, magnetic excitations, and the unexplored area of electronic transitions in the eV range. Experiments requiring higher momentum transfers will be possible. Pulsed sources also allow unique experiments that exploit the time structure of the neutron beam, such as studies involving pulsed ultra-high magnetic or electric fields, pulsed pressure or temperature. Commissioning the LANL proton storage ring in 1985 will permit more than ten times an increase in the intensity of pulsed neutrons available in the U.S.A.

The neutron flux of a pulsed source could be increased three or four times with a highly enriched uranium target. Examples of experiments that are not now possible for lack of sufficient intensity are in the area of molecular spectroscopy of internal modes and electronic transitions and exploitation of polarized neutrons. It is our current plan that IPNS will be phased out when the SNR/PSR at LANL on the IPNS user community can be effectively served there.

Synchrotron Radiation

Present: The past decade has witnessed an explosive growth in the use of synchrotron radiation for both basic and applied science. Synchrotron radiation facilities provide brighter and more tunable photon sources than photon sources available previously. The users community has expanded to include many disciplines--physics, chemistry, materials sciences, earth sciences, biology, and medicine. Materials scientists have been particularly active in investigating structural, electronic, and dynamic properties in a wide range of crystalline and amorphous materials using synchrotron sources for X-ray absorption, diffraction, photoelectron spectroscopy, microscopy, holography, topography, lithography, small-angle scattering, and fluorescence analysis.

Present experimental facilities for synchrotron radiation research in the United States include the new National Synchrotron Light Source at Brookhaven National Laboratory and the Stanford Synchrotron Radiation Laboratory (funded by DOE/BES), the Synchrotron Radiation Center at the University of Wisconsin and the Cornell High Energy Synchrotron Source (funded by NSF), and the Synchrotron Ultraviolet Radiation Facility at the National Bureau of Standards.

Future: Additional dedicated synchrotron radiation facilities must be provided in the coming decade to satisfy the expanding needs of researchers in materials science and other disciplines and to permit the exploitation of new opportunities in science and technology. First priority is the completion of projects already underway. These include commissioning of the X-ray ring at NSLS, which should be operational in 1985, and providing sufficient operating and research funds to take full advantage of existing facilities.

Insertion devices--wigglers and undulators--make possible orders of magnitude greater brightness than bending magnets. Construction of insertion-device beamlines has been approved as part of the Phase II project at NSLS and the Enhanced Photon Flux facility at SSRL. Future construction of additional insertion-device-based beamlines at existing remaining straight sections is also anticipated.

Major new facilities recommended for future construction include a high-energy storage ring providing fundamental undulator radiation in the hard X-ray region (to 20 keV) and a lower-energy ring providing fundamental undulator radiation in the soft X-ray region (to 2 keV) and having picosecond pulse timing capabilities. By consensus of the scientific community, high priority should be given to the high energy (6 GeV) ring.[1-3] (A European Synchrotron Radiation Facility having a 5 GeV ring has been under active consideration and design for several years; recently, Grenoble was selected as the site for this facility.[6])

A series of Synchrotron Radiation Facility Working Group meetings is planned. The first, to be held in October 1984, will plan and coordinate research and development leading up to the proposal stage for a 6 GeV facility. The objectives of these meetings are to set design goals, identify critical R&D issues, and to establish the timing, coordination, and resource allocation to implement this project. Construction costs are estimated to be $160 million (in FY 1985 dollars). Construction would take about 5 years. Construction of the lower-energy, short pulse ring could be started earlier (provided it did not delay the higher energy ring) and be completed in 4 years. This smaller ring would cost about $70 million (in FY 1985 dollars).

Electron Microscopy

Present: Electron microscopy and other techniques for obtaining visual images of and microchemical information on materials on a scale in the atomic to 10 nm range continue to be extremely important to materials science. Facilities today include: conventional transmission and scanning electron microscopes; atomic and high resolution electron microscopes that enable individual atoms and atomic planes to be observed; high voltage electron microscopes that allow thicker, less surface influenced specimens to be examined at high resolution; analytical electron microscopes that allow microchemical information to be obtained on specimens in the 10 nm range; and field ion microscopy/imaging atom probe (FIM/IAP) that allow study of atomic structure and microchemistry on an atom-by-atom basis.

Future: Three areas will be particularly important. First, to learn to exploit fully the capabilities embodied in current state-of-the-art atomic and high-resolution microscopes. These instruments are quite new and, in some cases, scarce (there is only one atomic resolution microscope in the United States--at LBL) and all the developments needed to exploit their full potential have yet to be made. These include computer software developments and research on electron interactions with matter. Second, to advance the state-of-the-art in analytical electron microscopy. Currently, spatial resolution is on the order of 10 nm and the quantitative accuracy is limited. Research and development is underway to obtain spatial resolution on the order of 1 nm and to improve the chemical quantitative accuracy. In addition, developments are needed to improve the usefulness of FIM/IAP to the study of materials. Currently, FIM/IAP is the only technique available where it is possible to chemically analyze a single atomic plane either on a surface or at internal interfaces. Third, advances are needed in environmental microscopy. It is possible to observe physical processes such as fracture or oxidation directly in an electron microscope while they are occurring. These studies place special requirements on microscopes and on interpretation of their images. They also require dedicated microscopes because of the specialized attachments that are necessary.

While the discussion so far has provided a glimpse of the state-of-the-art and the immediate future for electron microscopy, it is not always possible to predict what new developments will occur. For example, a limited amount of research has been carried out on scanning tunnelling microscopy where variations in electron tunnelling current between a fine probe and asperities on a surface enable atomic resolution of structural and chemical information to be obtained. If successful, this concept could open new vistas in studies of the electronic structure of surfaces and surface and interface characterization.

Center for Advanced Materials

The objectives of the Center for Advanced Materials are to perform high-quality, industrially responsive materials research, to educate future generations of scientists and engineers, and to accelerate the translation of basic knowledge into new technology. Because the research done by the Division of Materials Sciences to meet the needs of its energy mission is important and valuable to a large segment of U.S. industry, we plan to increase our efforts at technology transfer. (See Technology and Information Transfer, page 32.) The Center for Advanced Materials is a very important part of that plan. The site for the Center, Lawrence Berkeley Laboratory, is internationally renowned for its materials research. This laboratory is located next to the University of California, Berkeley, one of the world's outstanding institutions of higher learning in science and engineering.

High-quality research is assured by the staff of the Center, all outstanding scientists, state-of-the-art instrumentation, and the stimulus of the Berkeley environment. The program will be industrially responsive because the targeted research areas were developed and refined in several workshops[5] attended by representatives from major industries. The advisory committee of the Center also includes industrial representatives. The educational objective will be met as well. Graduate students will receive their training at the Center, and post-doctoral appointees will gain experience at the Center. These students and post-doctoral appointees will be trained in areas directly applicable to industrial research. Technology transfer will occur when the graduates of the Center's program are hired by industry, and by an industrial fellowship program for industrial scientists to do research at the Center.

The Center will consist of two new buildings, the Surface Science and Catalysis Laboratory and the Advanced Materials Laboratory. The scheduled completion date is 1988. The research program includes studies of ceramics, polymers, catalysis, advanced instrumentation for surface science, and electronic materials. In ceramics, the work will emphasize dispersion behavior of powder, consolidation, mechanical behavior, and wear. In polymers, the emphasis will be on liquid crystal polymers, polymer composites, polymer-solvent-nonsolvent interactions, and block copolymers. In catalysis, the emphasis will be on zeolites, transition metal compound catalysts, and novel materials in catalysis. The program on electronic materials will focus on mechanisms of defect formation in gallium arsenide and elucidation of the structure and electronic properties of interfaces between gallium arsenide and other materials. Development of scanning tunneling microscopy will also take place at CAM. Later additional topics will be considered such as forming of structural alloys and electronic interconnection technology.

23

RECENT PROGRESS AND ACCOMPLISHMENTS

During the past 5 years, significant progress and accomplishments have been achieved in the development of new techniques and facilities for the preparation, characterization, and analysis of new materials, the understanding of materials phenomena and properties, and the discovery of new materials and phenomena. Below is a brief description of some of the more notable examples.

Basic research has shown that during the irradiation of alloys, alloying elements interact sufficiently with defects produced by the radiation to cause segregation of the elements. This causes an initially homogeneous alloy to become heterogeneous or, in effect, a composite material. The engineering significance of this phenomenon to nuclear reactor alloy design is pervasive since the microstructure and, concomitantly, properties of the alloys will vary significantly during substantial fractions of their operating lifetimes. Recognition of the importance of this phenomenon to fission and fusion reactor materials development has occurred through numerous workshops, seminars and symposia. The findings of these basic studies have been successfully incorporated into many aspects of reactor materials development, and today they are providing an important underpinning to these materials development efforts.

In other radiation effects research, it has been predicted and discovered that nonenergetic helium atoms form lattice defects in metals and hence nucleate gas bubbles. This understanding alters present thinking on the role displacement-producing radiation plays in helium bubble formation in metals; this must be regarded as a potential problem area in fission and fusion systems. The importance of developing realistic radiation simulation methods has been demonstrated using dual ion beam irradiation to investigate the void swelling behavior of a model stainless steel. To simulate helium gas generation together with atomic displacements, as will occur in a fusion reactor first wall, samples are simultaneously bombarded with helium and heavy metal ions. All aspects of void formation (the kinetics as well as size and spatial distributions) are much different with this method than with the more common technique where helium is preinjected.

Research related to solar energy conversion has led to a number of significant results. Preparation of amorphous silicon by heating silane to 2,300 degrees centigrade with a tungsten source has resulted in the production of high quality material for solar energy conversion. It has been determined that atomic rather than molecular hydrogen is formed, and is responsible for the formation of more perfect bonds in silicon. In other solar related work, a method has been developed to control the di- and tri-hydride content in amorphous silicon hydride. Initial introduction of hydrogen into the amorphous silicon matrix forms silicon monohydride, which has a good photovoltaic response. As more hydrogen is added, however, di- and tri-hydrides form which degrade the photovoltaic properties. Whereas usual single-gap silicon cells have efficiencies in the range of 15 percent, basic research on multigap cells has demonstrated a total solar cell efficiency of 28.5 percent for a cell of aluminum-gallium arsenide in combination with a cell of silicon, i.e., for a two-band-gap solar cell. Simple, yet very high efficiency solar cells have been produced by glow discharge implantation doping of single crystal silicon followed by pulsed laser annealing. The method is easily automated and could radically change the manufacture of solar cells.

In the area of mechanical behavior and corrosion in energy systems, constitutive equations to describe creep deformation of metal alloys (e.g., in high temperature power plant components) have been developed. Pioneering work on zircaloy has elicited interest from the electric utilities' Electric Power Research Institute (EPRI). Specifically, EPRI provided material for determining the effects of crystallographic orientation on the behavior of zircaloy-4 fuel pin cladding in light water reactors, so that data needed to assess the validity of constitutive equations for design of reactor fuel pins can be gathered. Deviation from the expected constitutive behavior of zircaloy-4 suggests that a type of defect, grain boundary cavitation, is occurring. This result, confirmed by electron microscopy, helps explain premature cladding failures during power ramping of the reactors and offers guidance to future alloy development. It is known that high hydrogen pressures cause detrimental methane bubble formation in steels. In extreme cases this methanization has caused failure of pressure vessels in petrochemical plants similar to those planned for coal liquefaction. A model has been derived which shows the physical mechanisms controlling various states of bubble growth. An important practical implication of this work is that the bubbles can be removed by proper heat treatment. A common problem in welding stainless steel (used in many energy systems) is cracking at high temperatures. A study of the weld structure after various welding procedures has shown how the structure can be modified so that it is less susceptible to cracking. New research results on stress corrosion cracking (SCC) of alloys in aqueous solutions have shown the importance of borate ions (a threshold ratio of borate to thiosulfate ion) in inhibiting SCC. These results have provided guidance to the evaluation of intergranular SCC of nickel-base alloys in the Three-Mile-Island Unit 1 steam generator. Stress corrosion cracking tests on zircaloy demonstrated that radiation does not cause cesium iodide (the principal form of fission product iodine) to become an active agent and that cadmium probably is the fission product responsible for this form of failure of zircaloy cladding in light water reactors.

Analytical electron microscopy has been used to study the effectiveness of certain processing methods for preparing "synthetic rocks" that might provide stable hosts for radioactive waste storage. In one sample (SYNROC-A), an undesirable formation of a thin glass film separating the crystalline phases was detected. This film is undesirable because of its poor leaching resistance. The resultant structural information on these phases is being used to improve the processing methods. A study of simulated radioactive waste glass forms using uranium to substitute for transuranic elements has shown that they do not provide a reliable simulation of the structure and bonding properties of transuranics in silicate glasses. Since the leaching properties are dependent on bonding, this result indicates real waste systems must be investigated for reliable prediction.

In the area of embrittlement of materials, the preference of impurities to segregate to grain boundaries of different orientations has been established for the first time for the case of sulfur and oxygen in iron. This detailed information is a prerequisite for designing alloys with increased resistance to embrittlement. Other research has shown that cesium implanted into nickel binds strongly with hydrogen suggesting the use of cesium to prevent hydrogen embrittlement in critical components. Studies of steels have shown that brittle grain boundaries control fracture at low temperatures, and based on this effective alloy modifications and thermomechanical treatments have been used to inhibit this fracture mode. This may pave the way to future development of nickel-free alloys for use at low temperatures.

In the area of ceramic materials, a new method has been developed for the homogeneous addition of sintering additives to silicon nitride and a procedure derived to prevent the agglomeration of colloidal-sized powder. Homogeneity and retention of colloidal particle sizes are essential requirements to obtain reliable sintered silicon nitride components for systems such as ceramic engines. Fast ion conduction studies in lithium beta alumina by Raman scattering and model calculations have revealed that high conductivity results from correlated motions of ion pairs which indirectly move lithium ions into the conducting plane. These results are important for advances in the area of solid electrolytes in energy systems. In long-term elevated temperature tests, conditions have been identified under which a primary crack will grow based on its interactions with other smaller cracks and cavities in silicon nitride structures. This knowledge will provide guidance on acceptable flaw and phase distributions in high temperature structural ceramics and thus aid in developing realistic design criteria for high temperature energy system components such as large steam turbines or advanced gas turbines.

Research on ion implantation and laser annealing has resulted in a number of important findings. It has been demonstrated that the structure and surface hardness of ceramic surfaces can be modified and controlled by means of post-implantation thermal annealing. In other research, friction has been found to be greatly reduced at iron surfaces as a result of implanting with titanium and carbon ions. An amorphous ternary layer has been observed to form from the process. Materials with improved solar photovoltaic efficiencies have been synthesized. For example, single crystals of silicon implanted with arsenic and annealed with single laser pulses exhibit conversion efficiencies of 15.1 percent. Much cheaper polycrystalline silicon samples exhibit an efficiency of 12.1 percent, which is good for polycrystalline materials. This result is obtained primarily because of impurity profile control by laser annealing.

Several areas of theoretical research in the materials sciences have advanced through new insight and through the use of high-speed computers. In the area of electronic structure, computer modeling has successfully predicted the electronic band structure and structural properties of semiconductors based only on values of the atomic number of the constituent atoms. In a similar investigation, the electronic band structure of complex ternary photovoltaic compounds has been calculated. Both of these modeling techniques have the potential to predict how to tailor materials for optimum photovoltaic and other properties. A new phenomenon of magnetic field shielding that would reduce stray magnetic fields to the microgauss level has been calculated for a cylindrical superconducting device. The concept has been patented and has potential impact on supercomputer development as well as on greatly increasing the sensitivity for micromagnetic detection and measurement.

The difficult area of glassy solids has been successfully probed through computer simulation of the new phenomenon known as "quench-echoes" in these random materials. This result is important to understanding low-frequency excitations in glasses, which is an advancing field. Several theoretical studies of ultrarapid solidification processes are underway to understand the phenomenon of homogeneous bulk nucleation resulting from short-burst laser pulses on materials.

Amorphous or metallic glasses were discovered under a Materials Sciences contract and are now being developed for a number of applications including electrical transformer cores where their extremely low hysteresis loss may result in annual savings of 300 million dollars. Since these materials are normally produced by rapidly quenching liquid streams into thin solid ribbons, applications have been limited to those where ribbons can be used, in spite of the fact that the materials themselves possess significantly enhanced corrosion, mechanical and other properties over many normal crystalline materials. Follow-up investigations have recently shown that metallic glasses can be prepared at low temperatures without quenching by directly reacting crystalline materials with certain rapidly diffusing species. This discovery has at least two significant implications. First, from a scientific point of view, the discovery that equilibrium crystalline materials can be made to transform to nonequilibrium amorphous materials is exciting. Second, this discovery portends the possibility of preparing bulk (as opposed to thin ribbons) metallic glasses, thereby making metallic glasses with their enhanced properties accessible to a wider range of applications.

Until 1980 it was firmly believed that ferromagnetism and superconductivity, two forms of order in materials at low temperatures, were incompatible; that is, they could not coexist in the same material according to the prevalent theories of the day. However, measurements made in the mid-1970s of two unusual ternary compounds, erbium rhodium boride, and holmium molybdenum sulfide, suggested evidence for the existence of magnetism and superconductivity at temperatures below one Kelvin. In the early 1980s there was considerable research activity to determine the nature and interactions of the magnetism and the superconductivity in these two and other related compounds. Using neutron scattering it was found that for a small temperature range, ferromagnetism and superconductivity coexist in erbium rhodium boride. These and other new observations have contradicted the theories of the day and have given rise to improved theoretical understanding of both superconductivity and ferromagnetism.

Research on metallic alloys and compounds has resulted in a number of significant accomplishments. Unique electron microscopy facilities have made it possible to optimize the structure of steel for strength, fracture resistance and fabricability. As a result, a new class of dual phase steel alloys having greater strength and fracture resistance per unit weight and which can be fabricated using current commercial methods has been developed. The annual energy savings possible through weight reduction by using these dual-phase steels in cars, trucks, and trains may approach 10 percent of the 20 quads currently consumed by the transportation sector.

A new in-situ process has been developed for preparing multifilamentary superconducting wire at significantly reduced cost. Superconducting wire is used in magnets for NMR imaging, fusion energy research, and high energy physics and it has potential for use in power transmission and generation equipment. A class of materials called intermetallic compounds, such as Ni_3Al, which have excellent high temperature strength and corrosion resistance has been successfully fabricated by understanding principles of alloy thermodynamics and high temperature deformation. Heretofore, their use has been limited because of brittleness which has now been signficantly reduced. Research with niobium and tantalum covered with a few atomic layers of palladium has resulted in the discovery that hydrogen is absorbed at greatly increased rates compared with single atomic layer coverages or no palladium coverages at all. This discovery may assist efforts in large scale storage of hydrogen for energy systems.

Research on the synthesis of materials by deposition has resulted in a number of new materials. Using chemical vapor deposition (CVD), a hard, wear resistant coating of titanium diboride has been produced which shows promise for use in valves in coal liquefaction. The technique developed is capable of depositing adherent, porous-free titanium diboride which exhibits excellent erosion resistance. Also using CVD, an important, new high-temperature solar-absorbing film has been synthesized. The material, zirconium diboride, shows excellent long-term stability in air at $600^\circ C$. Using electric-field-induced sputtering, fabrication of complex ceramic coatings has been shown possible by understanding the relationship between sputter parameters and microstructure. This understanding has permitted the formation of coatings containing controlled chemical composition (graded from metallic to ceramic at the outer edge) and structures that are capable of withstanding severe thermal cycling. Low energy deposition of very low concentrations of platinum on surfaces of titanium (about one atom in a thousand) has resulted in two dimensional arrays of platinum possessing high surface areas and enhanced catalytic activity; this offers potential guidance for designing low-cost catalysts.

Research on materials characterization and instrumentation has led to a number of significant developments. Two triple-axis superconducting quantum interference devices (SQUID), devices capable of measuring minute changes in the earth's magnetic field, have been successfully deployed 4.8 kilometers apart near the San Andreas Fault in California. With this ultra-sensitive apparatus, long-term monitoring of the earthquake zone can take place and the onset of earthquakes may be predicted. Developments in new sophisticated instrumentation with SQUIDs have resulted in devices that operate at temperatures of about 16K, the highest yet reported. These devices are especially sensitive for deep earth geothermal exploration (more than 10 km) at low frequencies (less than 10 Hz). Actual field tests in a known geothermal area have correlated a geological fault line sequence with a known source and have predicted new source areas which will soon be explored for confirmation. Recent extensions of this technique are being applied to the location of hydrofractures for advanced gas and oil recovery.

Using radiation from a synchrotron radiation source, the surface structure and temperature distribution for silicon during and following laser heating were determined for the first time. By combining the probes of small angle neutron and X-ray scattering, the size, shape, and pore distribution of oil contained in oil shale have been determined nondestructively for the first time. These techniques will greatly assist the development of extraction technology as well as enhanced oil recovery schemes.

New diagnostics using photoemission have been applied to battery systems, especially electrolyte solutions, where as little as 2 parts per billion iodine has been detected at the liquid surface. These same studies, which make use of the newly discovered Giant Raman Effect, have identified adsorbates under water; this has not been possible to accomplish with standard spectroscopic techniques such as infrared or electron energy loss spectroscopy.

Neutron "time-of-flight" techniques have been successfully used to measure residual stresses in tungsten carbide cermet materials and in a zirconium alloy. The information on cermet materials is important in the design and development of drilling inserts for oil and gas well drilling apparatus. The detailed information on residual stresses in the zirconium alloy provides valuable data for reactor fuel element and pressure tube design and performance analyses.

Development of a portable infrared detection instrument makes possible real-time rapid airborne study of plume chemistry which will help control acid rain. A real-time airborne analysis above a coal-fired power plant plume has been conducted for the first time and revealed unusual sulfate particle distributions over short-time periods (as little as thirty minutes after leaving the stack) and over considerable distances (tens of miles).

CONSULTATION, REVIEW, AND COORDINATION

The Division of Materials Sciences seeks information from many sources to help define the program and chart its course. There are three main categories of information:

(1) Information regarding research specific to DMS--The sources for this type of information include the Council on Materials Science, special Divisional workshops, peer reviews of unsolicited proposals and DOE Laboratory research proposals, plans, reviews, and information meetings.

(2) Information regarding Materials research and institutional issues involving more than one Office or Assistant Secretary within the Department of Energy--The Energy Research Advisory Board, Research Assistance Task Forces, and jointly sponsored contractors meetings and workshops provide this type of information.

(3) Information regarding Materials Research as a discipline and interagency institutional issues--The National Research Council, OSTP, OTA, and interagency coordinating groups provide information on these issues.

Each of these categories has its history and reasons for existence. Taken together, they ensure that the Division of Materials Sciences research program is appropriate for its mission, at the scientific forefront, and coordinated with the Department of Energy and the rest of the Federal Government. Our plans are to continue to consult with and seek reviews from the scientific community in industry, universities, and government to strengthen our commitment to excellence and to coordinate the research program with other Federal research programs. In the two sections below these efforts are described in detail.

Consultation and Review

In 1977, a series of workshops[7] were sponsored by the Division of Materials Sciences to recommend future directions in energy related materials research. One conclusion was that there was a need for a forum for the continuing assessment and stimulation of various research areas. In response to this conclusion the Council on Materials Science was established in March of 1978. The charter of the Council directs it "to conduct scholarly studies and reviews of topics of interest for materials sciences and DOE" and "to act as a sounding board for new concepts and a source of expert opinions to the Division of Materials Sciences."[8] The Council has a steering committee of about seven members with a rotating membership and a maximum term of 3 years. Annually, this steering committee decides on study areas, usually two, to be pursued during the year, and selects a panel of experts for each study area.

The panel members are selected from universities, industry, national laboratories, and government laboratories. Since 1979, one hundred and sixty-three scientists and engineers have participated in these panels. Sixty-two came from universities, 55 from national laboratories, 40 from industry and 6 from non-DOE government laboratories. Considering the time required for preparation, the panel meeting itself, and the writing of a report after the meeting, this effort is equivalent to about 6 person years.

The panel of experts meets usually for a week for an in-depth study of an area and prepares a report which is submitted to the Division of Materials Sciences. These reports are of such caliber that most have been published in the scientific literature. A list of these reports is included in the Appendix.

Divisional workshops are also sponsored as appropriate to deal with specific topics of current interest. These activities also serve to bring together scientists working on common problems but with different methods and viewpoints. Often these workshops or panels deal with issues involving major facilities. For example, in 1980 a panel was convened to review neutron scattering and in 1982 another panel was convened to review pulsed neutron research. In 1984, a planning group for advanced national synchrotron radiation facilities was convened. Other workshops deal with research topics that for various reasons become important. Examples include the workshop on fracture of materials at elevated temperatures held in 1979; and the workshop in 1983 on critical and strategic materials. A list of these workshops and panels is given in the Appendix.

Reviews of unsolicited proposals are a very important and extensive source of advice. About 300 of these proposals are received annually. Each is sent to about four experts for review. The reviews are one of the most important factors that determine whether or not a proposal is funded. Since these proposals are unsolicited, the ones that are funded affect the direction and content of the research program. National laboratory proposals, reviews, and information meetings affect the program in a similar way.

The Energy Research Advisory Board advises the Secretary of Energy. Many of its reports deal with issues pertinent to materials research such as the report "Materials Research and Development" issued in 1983. Others deal with institutional issues such as the report "The Department of Energy Multiprogram Laboratories." A list of these reports is given in the Appendix. Materials related problems occur throughout the Department of Energy. Recommendations on the solution of these problems is sought through Research Assistance Task Forces (see later discussion) supported jointly by the Division of Materials Sciences and other interested offices in the Department. These task forces have dealt with fuel cells, batteries, and radioactive waste. A list of these task force meetings is given in the Appendix.

Materials research is supported by many agencies of the Federal government, such as DOD, DOC, NSF, DOE, etc. Although each of these agencies has specific needs, materials research, like all scientific research, transcends narrow purposes. Often needs overlap such as in the case of large facilities. Materials research as a discipline and as a whole throughout the government receives guidance by the National Academy of Sciences and the National Academy of Engineering through the National Research Council and the National Materials Advisory board. Many of the studies by these organizations are supported by the Division of Materials Sciences, often jointly with other agencies. A list of such reports is given in the Appendix. From time to time, commissions are charted to advise the President's science advisor or the President. Some, such as the "Packard" and "Grace" commissions, also contain recommendations pertinent to the Division of Materials Sciences.

Coordination

Coordination takes place at various levels including individual contacts and exchange of documents among researchers in the usual scientific mode. The Since the early 1960's the Division has compiled an annual listing and index of the programs it supports . The listing is distributed widely to other agency personnel and to researchers in the field. In areas of high visibility, research bulletins are published and exchanged among researchers to keep them up to date on the latest findings and plans. Within the Department of Energy, the materials research programs are coordinated in a formal way through the Energy Materials Coordinating Committee and its various sub-committees. An annual technical report is compiled and published. At the Federal agency level, many formal committees exist. The Interagency Committee on Materials coordinates the programs of the funding agencies for basic materials research. A number of topical committees exist, such as the Interagency Ceramics Committee and the Interagency Intense Photon Source Committee. At the OSTP level, the Committee on Materials (COMAT) assists in coordinating the Federal programs in materials, both basic and applied. COMAT has sub-committees on welding, rapid solidification technology, and essential materials. The Division of Materials Sciences is an active participant on all these coordinating bodies.

In interfacing with the DOE applied programs, a formal mechanism has been established called the Research Assistance Task Force (which is also a source of recommendations as stated above). Where an area of mutual interest has been identified by both the basic research program and the applied program, a meeting is held to bring together researchers from both programs for the purpose of exchanging views and identifying further research to be undertaken. These meetings have been successful in coordinating the basic and applied research within the Department.

This is only a brief summary of activities aimed at assuring a high quality well coordinated program.

TECHNOLOGY AND INFORMATION TRANSFER

The transfer of technology discovered or developed in Federal research programs has been a topic of increased interest and concern. The subject is important, and the concern is appropriate. Federal research should benefit society and can do so by advancing technology in U.S. industry. In the 36 years that the Division of Materials Sciences has been in existence, it has been an effective contributor to technology used by industry. In the future we plan to increase and intensify our efforts to transfer technology and information. Industry will be made aware early of research that may lead to technological development.

There have been many examples of direct transfer of our research to industry. The first commercial process for the separation of samarium, which is used to make samarium cobalt magnets was developed at Ames Laboratory. In 1971 this process accounted for 99 percent of total world production of samarium metal. The separation of rare earth elements used for phosphors in television sets, which was mentioned under Research on page 10, is another example of technology transfer from Ames. Zirconium used in Zircaloy for nuclear fuel cladding is separated from hafnium with another Ames process. The High Flux Beam Reactor was used by scientists from Bell Laboratories in collaboration with scientists at Brookhaven to make measurements that described magnetic bubble domains that led to high-density computer memories. Radiation resistant alloys were developed at Oak Ridge National Laboratory. Channelling phenomena, which was predicted and discovered at Oak Ridge National Laboratory, is now used in industry to determine profiles and lattice sites of implanted ions. Other industries have used channeling to manufacture solid state detectors. A process for purifying calcium, which was developed at Ames, was adopted by the New England Lime Company, a Division of Pfizer, Inc., and is used to prepare the major part of the calcium used in the U.S. today. The metal has important applications in steel production, metal reduction, and the lead-calcium battery industries. Low Temperature Research at the University of California at La Jolla and Los Alamos led to the development of the He^3-He^4 Dilution Refrigerator which is marketed by the S.H.E. Corporation world-wide. Metallic glasses, that is non-crystalline metals, were discovered at the California Institute of Technology. These materials are now being developed for many applications including low-loss cores for electrical transformers and motors by Allied Chemical and General Electric Companies, respectively. Just this year, at the California Institute of Technology it was discovered that metallic glasses can be made at low temperatures without rapidly cooling molten metals by directly reacting crystalline materials with certain rapidly diffusing species. With this discovery, it may be possible to prepare bulk metallic glasses instead of the thin ribbons made by quenching rapidly molten metals. STREM Chemicals of Newburyport, Massachusetts, has acquired the process for synthesizing superconducting TMTSF organic donor material from the synthesis discovery at Argonne National Laboratory. The material is now being synthesized and sold around the world. Research on superconducting quantum interference devices (SQUID) at Lawrence Berkeley Laboratory has led several companies to use the device and technique in oil and geophysical exploration including earthquake detection. Research on glass leaching at Pacific Northwest Laboratories related to nuclear waste disposal showed that the surface of glass in water has a very high negative potential while polymers have essentially zero potential. These observations led to a method for testing for uniform coating of glass with polymers. Johnson and Johnson now uses the method for their glass-reinforced, polymeric dental filling material.

Even though the economic value of transferred technology in terms of annual sales exceeds the budget of the Division of Materials Sciences by a large margin, these direct transfers of our research to industry are not the most important contribution to the Nation's technological progress. The more important and widespread transfers of technology are indirect and impossible to quantify. These indirect transfers occur whenever a student receives a degree through one of our research programs and is hired by industry. In 1983, about 180 students supported by Materials Sciences were awarded Ph.D. degrees. Whenever an industrial scientist reads the scientific literature on materials, chances are that knowledge is transferred. During the last 5 years, our research has produced over 8,000 scientific and technical publications. Facilities supported by Materials Sciences are being used by industry. Industrial investment at the NSLS exceeds 5 million dollars for example; 14 percent of the users of the Centers for Collaborative Research were industrial scientists in 1983.

During the next 10 years, we expect technology transfer to increase because the Division of Materials Sciences has given early and long-standing support to advanced or "high-tech" materials. Indeed, our program discovered some of them, such as amorphous metals. Sales of advanced ceramics are expected to reach $12 billion in 1990[10]. In some areas, the Europeans and Japanese have caught up with our early lead. For example, even though the technique of neutron scattering was discovered and to a large extent was defined by this program, the Institute Laue-Langevin in Europe can accommodate more users and has more instruments (some which are not available in the U.S.) than all of our neutron scattering facilities combined; and neutron scattering is a very important component of the materials research program that has made possible the "high-tech" revolution in materials. U.S. industry faces stiff international competition, and the research program of the Division of Materials Sciences will help U.S. industry increase its competitive edge.

Now that many of the institutional barriers, such as patent and proprietary rights, have been removed or lowered, we can concentrate on what we have determined is the key problem--awareness. Technology will not be transferred unless industrial scientists are aware that it exists and are willing to exploit it. Too often other nations such as Japan have made use of discoveries made in the U.S. (some originating in our program) before U.S. industry. We do not know why; but we can encourage participation of U.S. industrial scientists and technical managers in our research program so that they will be aware, early, of exciting research and technological developments.

We plan to increase the dialogue between industrial researchers and researchers that we support at National Laboratories and Universities by increasing industrial representatives in panels, workshops, seminars, and other meetings. We will encourage the managements of the National Laboratories to do the same. We are not breaking new ground. As was pointed out in Consultation, Review, and Coordination on page 29, our Council on Materials Sciences has had about 25 percent of its panel members from industry. Also the planning study for advanced national synchrotron radiation facilities was co-chaired by P. Eisenberger from Exxon, and a symposium on polymer research at synchrotron radiation sources is co-sponsored with IBM and chaired by T. P. Russell from IBM. Industrial participation in the Collaborative Research Centers will be increased. The Center for Advanced Materials is an important part of the plan. This Center is organized with the intent to have industrial, university, and national laboratory scientists and engineers working together. Ph.D. candidates and post doctoral fellows will work with industrial scientists and be better prepared for industrial research.

Our most important contribution to technology transfer will be to maintain a first class materials research program with accessible state-of-the-art instrumentation. Our primary responsibility will be to increase knowledge. The "high-tech" materials of today are the harvest of seeds sown during the past three decades. We are now seeding for the "high-tech" materials of the coming century. Our obligation will be to share that knowledge so that industry can use it to improve and make new commercial products.

FUNDING REQUIREMENTS

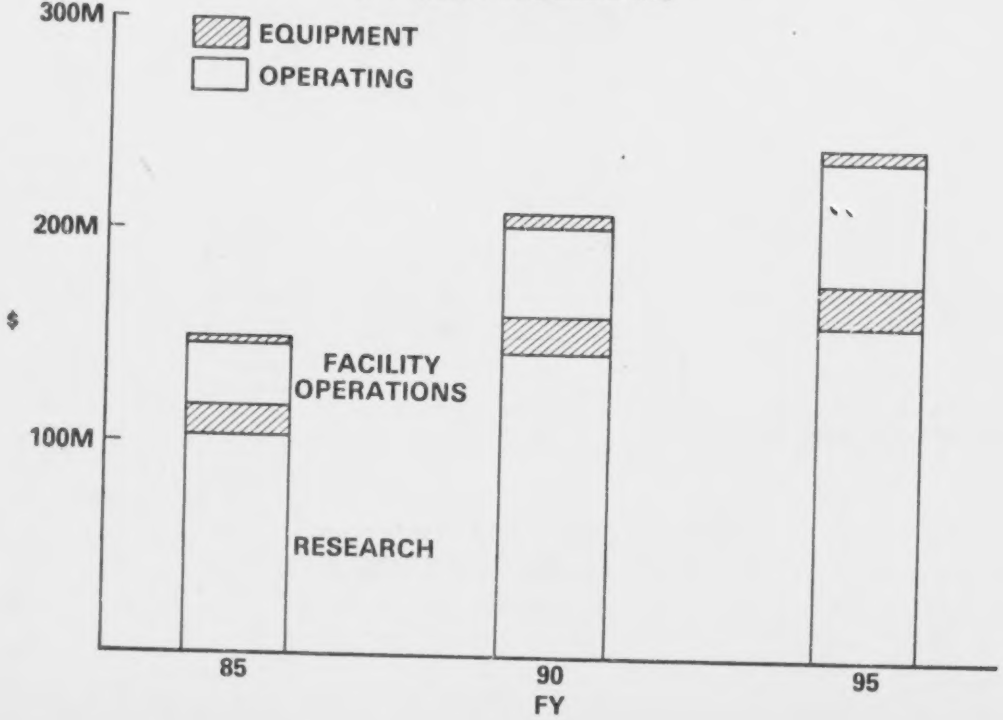
Funding for the Materials Sciences long range program plan must incorporate the following elements: 1) a core research program which provides support locally for the best researchers undertaking forefront materials research regardless of where the research is undertaken, at a facility or elsewhere, 2) a facility support program which adequately provides support for the operation of major user or collaborative research centers, and 3) a construction program for the purpose of providing major new or upgraded instruments and facilities needed by the research community. Projecting these elements into the future, the following funding trend is needed: a) for the core research program, a modest overall growth is needed with stronger selective strengthening in areas such as materials synthesis and preparation and research at major new facilities as they become operational, b) a more substantial growth in the operational funding of major user facilities so as to make them "user-friendly" to the wide range of university, industrial, and laboratory researchers, and c) a significantly greater commitment to constructing the future forefront facilities on which the materials sciences program of the future will rest. As priorities become settled on these new major facilities, decisions will also have to be made on the continued support of all of the older facilities. All factors, including obsolescence, user needs, program balance, and funding realities, will be carefully considered in these decisions.

The charts which follow, provide a visual display of the funding requirements for this long range plan through FY 1995.

8/24/84

Figure 1

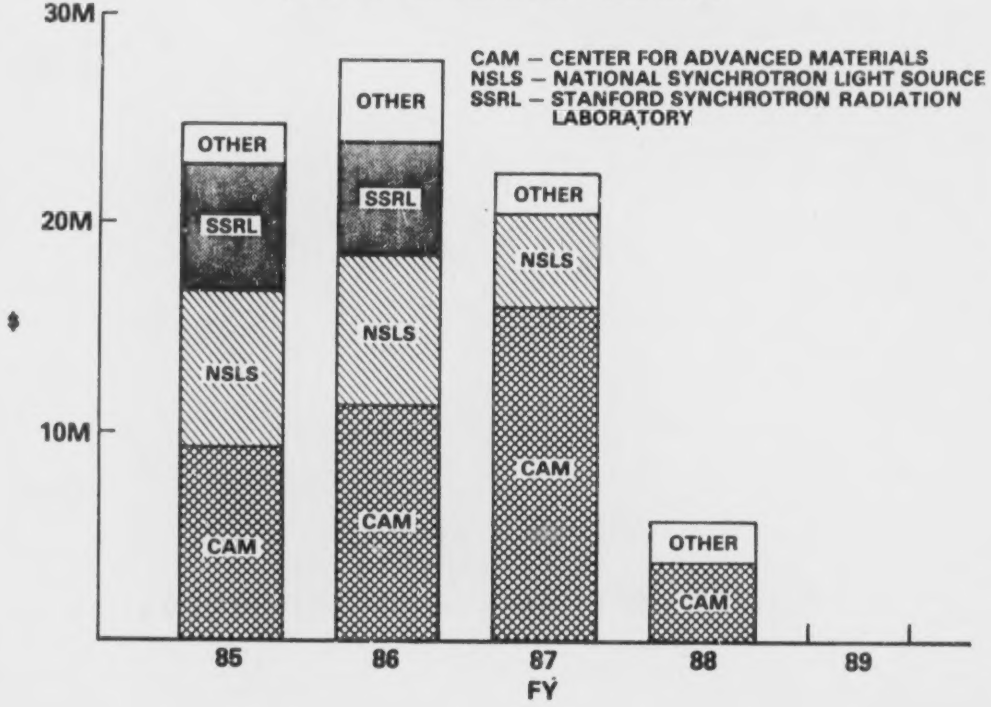
FUNDING FOR RESEARCH AND FACILITY OPERATIONS
(FY 1985 DOLLARS)



8/24/84

Figure 2

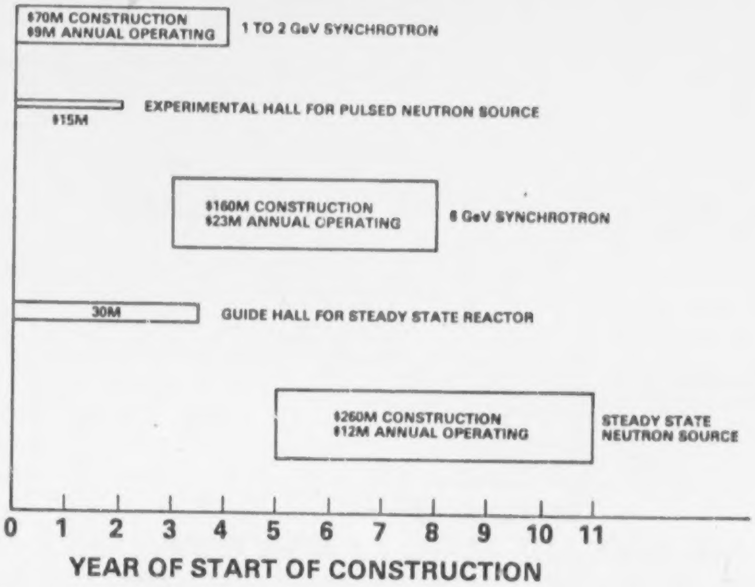
APPROVED CONSTRUCTION
(ACTUAL YEAR DOLLARS)



8/24/84

Figure 3

FUTURE CONSTRUCTION PROJECTS REVIEWED AND RECOMMENDED
(AREAS PROPORTIONAL TO CONSTRUCTION COSTS IN FY 1985 DOLLARS)

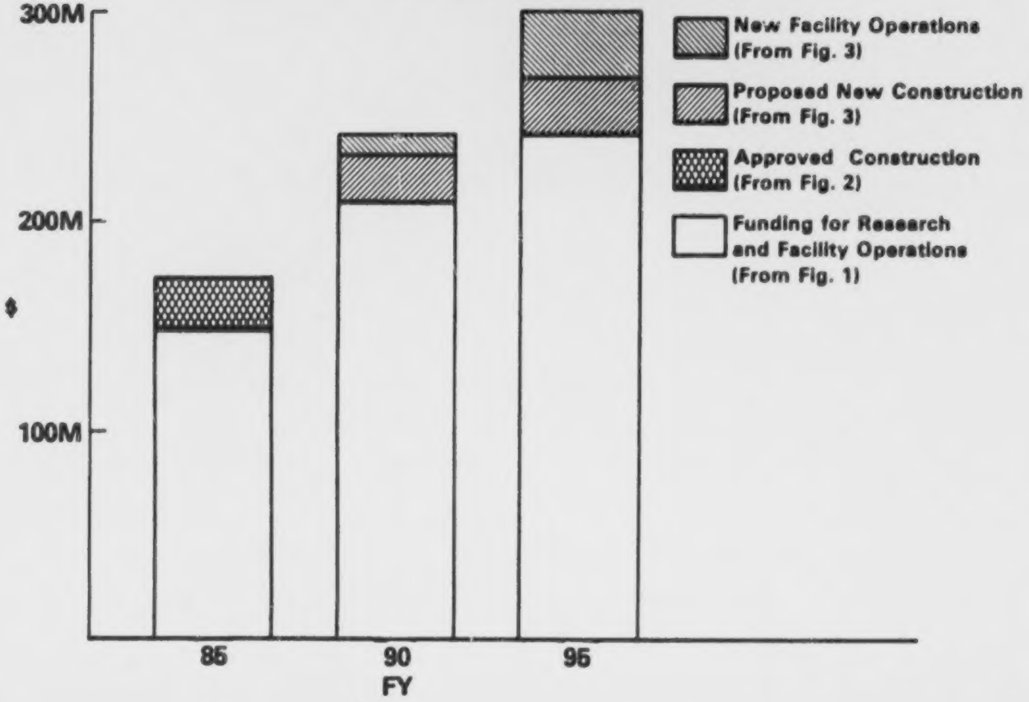


This figure displays funding for the possible construction projects which have been reviewed and recommended by one or more committees. The projects which are shown to start now (time = 0) represent ones which in addition have received approval from DOE to be forwarded in the budget process. In other words, these projects are ready for construction as soon as funding becomes available. The figure does not attempt to state priorities within a certain restricted funding level.

8/24/84

Figure 4

TOTAL BUDGET INCLUDING APPROVED AND PROPOSED NEW CONSTRUCTION AND NEW FACILITY OPERATIONS
(FY 1985 DOLLARS)



REFERENCES

1. NRC Major Facilities Committee, "Major Facilities for Materials Research and Related Disciplines," National Academy of Sciences, Washington, DC, 1984.

2. NRC Solid State Sciences Committee, Panel on Neutron Scattering, "Current Status of the Neutron-Scattering Research and Facilities in the United States," National Academy of Sciences, Washington, DC, 1984.

3. National Synchrotron Radiation Planning Committee, "Planning Study for Advanced National Synchrotron-Radiation Facilities," Sandia National Laboratories, Albuquerque, NM, March 14, 1984.

4. DOE Ad-Hoc Committee, "Report on the Brookhaven National Laboratory National Synchrotron Light Source," AT-DO: 84-157 (Rev.), Los Alamos National Laboratory, Los Alamos, NM, 1984.

5. Six workshops were held in 1983. Reports listed below are available.

   "Report of the NCAM Industry Participation Workshop," PUB-5101, Lawrence Berkeley Laboratory, Berkeley, CA, 1983.

   "Workshop on CAM Program on Metal Compounds as Catalysts," PUB-5106, Lawrence Berkeley Laboratory, Berkeley, CA, 1983.

   "Workshop on CAM Program on Polymers and Polymer Composites," PUB-5107, Lawrence Berkeley Laboratory, Berkeley, CA, 1983.

   "Workshop on Metallurgy: Structural Alloys and Electron Interconnection Technology," PUB-5108, Lawrence Berkeley Laboratory, Berkeley, CA, 1983.

   "Workshop on the Electronics Materials Program," PUB-5110, Lawrence Berkeley Laboratory, Berkeley, CA, 1983.

   "Workshop on Advanced Structural Ceramics," PUB 5125, Lawrence Berkeley Laboratory, Berkeley, CA, 1984.

6. Science, 226, 524 (1984)

7. "Materials Sciences Overview I. Executive Summary," ERDA 77-76/1, and "Materials Sciences Overview II. Workshop Reports," ERDA 77-76/2, Washington, DC, 1976. The nine workshops were Electronic, Magnetic, Optical, and Thermal Properties; Surface Science; X-ray, Neutron and Electron Scattering; Low Temperature Research and Superconductivity; Phase Transformations, Stability and Materials Interactions; Defects, Diffusion, and Radiation Effects; Engineering Materials Science; Mechanical Properties; and Thermodynamics and Electrochemistry.

8. Memorandum, D. K. Stevens to J. S. Kane, March 6, 1978

9. "Materials Sciences Programs Fiscal Year 1984," DOE/ER-0143/2, September 1984. (Published annually since 1968.)

10. Chemical and Engineering News, July 9, 1984, p. 26

APPENDIX - REPORTS FROM PANELS, WORKSHOPS, RESEARCH TASK FORCES, NATIONAL ACADEMY AND ENERGY RESEARCH ADVISORY BOARD PERTINENT TO MATERIALS SCIENCES SINCE 1979.

I. Reports from the Council on Materials Sciences

1. "High Temperature Ceramics," January 1979, chaired by K. Bowen, Massachusetts Institute of Technology.
2. "Theory of Surfaces," January 1979, chaired by D. R. Hamann, Bell Laboratories.
3. "Corrosion in Energy Systems," June 1979, chaired by R. A. Rapp and D. D. MacDonald, Ohio State University.
4. "New Materials," November 1979, chaired by T. H. Geballe, Stanford University.
5. "Nondestructive Evaluation of Materials," September 1980, chaired by J. E. Gubernatis, Los Alamos National Laboratory and J. A. Krumhansl, Cornell University.
6. "Amorphous Materials," December 1980, chaired by W. L. Johnson, California Institute of Technology and F, L. Galeener, Xerox Palo Alto Research Center.
7. "The Effects of Irradiation on the Structure and Properties of Materials," July 1981, chaired by C. P. Flynn, University of Illinois.
8. "Future Trends in Condensed Matter Theory and the Role and Support of Computation," December 1981, chaired by J. D. Joannopoulos and A. N. Berker, Massachusetts Institute of Technology.
9. "High Pressure Science and Technology," July 1982, chaired by G. A. Samara, Sandia National Laboratories.
10. "Technology of Nuclear Waste Containment," July 1982, chaired by D. Turnbull, Harvard University.
11. "Coatings and Surface Modifications," March 1984, chaired by R. L. Schwoebel, Sandia National Laboratories.

II. Workshops and Panel Reports Sponsored by the Division of Materials Sciences

1. "Thin Film Problems and Research in Energy Systems," January 1979.
2. "Time Dependent Fracture of Materials at Elevated Temperature," June 1979.
3. "The Analysis of Hydrogen in Solids," April 1979.
4. "Alternate Nuclear Waste Forms and Interactions in Geologic Media," April 1981.
5. "Basic Research Needs and Opportunities on Interfaces in Solar Materials," April 1981.
6. "Report of the Review Panel on Neutron Scattering," 1980.
7. "Report of the Pulsed Neutron Research Review Committee," 1982.
8. "Report of the Working Group on Low Temperature Neutron Irradiation," July 1982.
9. "Materials Preparation and Characterization Capabilities," February 1983.
10. "Critical and Strategic Materials," June 1983.
11. "Planning Study for Advanced National Synchrotron-Radiation Facilities," March 1984.
12. "Report of the DOE Ad-Hoc Committee on the Brookhaven National Laboratory National Synchrotron Light Source," 1984.
13. "Observation and Identification of Crack Growth Modes in Reactor Steels Using Acoustic Emission," 1984.

III. Research Assistance Task Force Reports

1. "Solid Electrolyte Secondary Batteries," April 1979, with the Division of Energy Storage Systems.
2. "Canisters for Radioactive Waste," May 1979, with Nuclear Waste Management.
3. "Hydrogen in Sterling Engines," May 1980 with Automotive Technology Development Division.

4. "Metal Air Battery," June 1980 with Advanced Conservation Technologies.

5. "Molten Carbonate Fuel Cell Materials," April 1981 with Office of Coal Utilization.

6. "Structural Behavior of Repository Materials," May 1981 with Strategic Petroleum Reserve and Nuclear Waste Management.

7. "Beta-Alumina for Sodium-Sulfur Batteries," June 1983 with Electrochemical Storage Branch, Office of Energy Systems.

IV. National Academy Reports

1. "Synthesis and Characterization of Advanced Materials" (1984).

2. "Microstructure Science, Engineering and Technology" (1979).

3. "Support of Small Research Projects in Materials Science at Universities" (1979).

4. "High-Magnetic-Field Research and Facilities" (1979).

5. "An Assessment of Trends in Solid State Sciences" (1980).

6. "Polymer Science and Engineering Challenges, Needs, and Opportunities" (1981).

7. "The Free Electron Laser" (1982).

8. "Fostering Increased Cooperation Between the Geological and Materials Sciences" (1982).

9. "Current Status of Facilities Dedicated to the Production of Synchrotron Radiation" (1983).

10. "Muon Sources for Solid State Research" (1984).

11. "Current Status of Neutron-Scattering Research and Facilities in the United States" (1984).

12. "Major Facilities for Materials Research and Related Disciplines" (1984).

V. Energy Research Advisory Board Reports

1. "Research and Development Needs in the Department of Energy," September 1980.

2. "Federal Energy R&D Priorities," November 1981.

3. "The Department of Energy Multiprogram Laboratories," September 1982.

4. "An Assessment of the Relationships Between the Department of Energy and Universities and Colleges, Volume I," August 1983.

5. "An Assessment of the Relationship Between the Department of Energy and Universities and Colleges, Volume II," October 1983.

6. "Materials Research and Development," November 1983.

Major Facilities for Materials Research and Related Disciplines

Major Materials Facilities Committee
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, DC 1984

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences the the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

Support for this project was provided by the Department of Energy under Grant No. DE-FG01-84ER45062 and by the National Science Foundation under Grant No. DMR-8408982.

Available from
Major Materials Facilities Committee
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

NATIONAL RESEARCH COUNCIL

2101 CONSTITUTION AVENUE WASHINGTON, D. C. 20418

OFFICE OF THE CHAIRMAN

July 24, 1984

Dr. George J. Keyworth, III
Director
Office of Science and Technology
Policy
Old Executive Office Building
Washington, D.C. 20500

Dear Jay:

I am pleased to transmit a report on major materials facilities, prepared at your request by a committee of the National Research Council (NRC). As with all reports of the NRC, the report is the responsibility of its committee, but its review has been monitored by the Academies' Report Review Committee.

The report presents priorities both for new facilities and new capabilities at existing facilities with initial cost of at least $5 million. The new facilities in order of priority are: a 6 GeV Synchrotron Radiation Facility; an Advanced Steady State Neutron Facility; a 1 to 2 GeV Synchrotron Radiation Facility; and a High Intensity Pulsed Neutron Facility. The new capabilities at existing facilities in order of priority are: centers for cold neutron research, incorporating guide halls and instrumentation; insertion devices on existing synchrotron radiation facilities; an experimental hall and instrumentation at the Los Alamos National Laboratory Pulsed Neutron Source; upgrading of the National Magnet Laboratory; and enriched pulsed neutron targets.

The context for these recommended priorities is given in the executive summary, and more fully set out in the three chapters of the report proper. Chapter I titled, Materials Research: Facilities and Modes, describes the nature of materials research, by whom it is done, and for what purposes; and the major facilities for synchrotron radiation, neutron scattering, and high magnetic field research, in the United States and other countries. Chapter II titled, Major Materials Facilities: Science and Technology, outlines the research that has been done with existing facilities and that will be facilitated with the proposed new installations. Chapter III titled, Conclusions and Recommendations, offers a fuller rationale for the priorities, briefly analyzes costs, and surveys facilities considered but not included in the priorities by virtue of the Committee's charter and without necessarily passing any judgment on their relative merit.

As acknowledged in the preface to the Report, setting priorities was a "difficult and painful" task for the Committee. It should be understood that, in accordance with your request, the report did not address the question of balance between support for "small" and "big" science in materials research. The Committee hewed to its charter: to set priorities among major facilities considered important to the nation's research efforts. Therefore, the report should not be read as advocating increased support for major facilities to the detriment of smaller scale science, typically done at universities, governmental laboratories, or regional centers. Indeed, quoting from the preface, "additional panels should be convened to address other aspects of materials resarch and to review previous recommendations in light of new information."

With those caveats in mind, I believe this report to be a major contribution to guiding the science and technology of the United States. All of us understood that selecting priorities is a difficult task. That it was done, with care and wisdom, is due to the members of the committee, to its staff, and to the Committee's leaders, Frederick Seitz and Dean Eastman.

I commend the report to your attention.

Sincerely,

Frank

Frank Press
President

Attachment

MAJOR MATERIALS FACILITIES COMMITTEE

Dean E. Eastman, IBM (Co-Chairman)
Frederick Seitz, Rockefeller University (Co-Chairman)
Richard B. Bernstein, University of California, Los Angeles
Robert J. Birgeneau, Massachusetts Institute of Technology
Jerome B. Cohen, Northwestern University
Mildred S. Dresselhaus, Massachusetts Institute of Technology
Harry G. Drickamer, University of Illinois
Peter Eisenberger, Exxon Research and Engineering Company
Donald Engelman, Yale University
Walter Kohn, Institute of Theoretical Physics, Santa Barbara
David W. Lynch, Iowa State University and Ames Laboratory
Albert Narath, AT&T Bell Laboratories
William D. Nix, Stanford University
Edward Rubenstein, Stanford University Medical Center
John J. Rush, National Bureau of Standards
Albert I. Schindler, Naval Research Laboratory
Arthur Sleight, E.I. du Pont de Nemours & Company, Inc.
William P. Slichter, AT&T Bell Laboratories
Joseph V. Smith, University of Chicago
Richard Stein, University of Massachusetts
H. Guyford Stever, Universities Research Association
John M. White, University of Texas at Austin

Neutron Scattering Panel:

Robert J. Birgeneau (Chairman)
Jerome B. Cohen
Mildred S. Dresselhaus
Donald Engelman
John J. Rush
Joseph V. Smith
Richard Stein
Michael E. Fisher, Cornell University (Consultant)

Synchrotron Radiation Panel:

David W. Lynch (Chairman)
Richard B. Bernstein
Jerome B. Cohen
Donald Engelman
Edward Rubenstein
Joseph V. Smith

Other Specialized Materials Facilities Panel:

Albert Narath (Chairman)
Richard B. Bernstein
Jerome B. Cohen
Mildred S. Dresselhaus
Walter Kohn
William D. Nix
Albert I. Schindler
Arthur Sleight
William P. Slichter
Richard Stein
H. Guyford Stever
John M. White

Budget Panel:

H. Guyford Stever (Chairman)
John J. Rush
Albert I. Schindler

National Research Council Staff

William Spindel, Staff Director
Norman Metzger, Editor
Robert Park, Consultant
Peggy J. Posey, Staff Associate
Robert M. Simon, Staff Officer
Jean E. Yates, Administrative Secretary
Pamela S. Klages, Secretary

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

Herbert Friedman, National Research Council, Chairman
Elkan R. Blout, Harvard Medical School
Bernard F. Burke, Massachusetts Institute of Technology
Herman Chernoff, Massachusetts Institute of Technology
Mildred S. Dresselhaus, Massachusetts Institute of Technology
Joseph L. Fisher, Office of the Governor, Commonwealth of Virginia
James C. Fletcher, University of Pittsburgh
William A. Fowler, California Institute of Technology
Gerhart Friedlander, Brookhaven National Laboratory
Edward A. Frieman, Science Applications, Inc.
Edward D. Goldberg, Scripps Institution of Oceanography
Mary L. Good, UOP, Inc.
Charles J. Mankin, Oklahoma Geological Survey
Walter H. Munk, University of California, San Diego
George E. Pake, Xerox Research Center
Robert E. Sievers, University of Colorado
Howard E. Simmons, Jr., E.I. du Pont de Nemours & Company, Inc.
Isadore M. Singer, University of California, Berkeley
John D. Spengler, Harvard School of Public Health
Hatten S. Yoder, Jr., Carnegie Institution of Washington

Raphael G. Kasper, Executive Director

PREFACE

The President's Office of Science and Technology Policy in November 1983 asked the National Research Council (NRC) to assist in establishing priorities for major facilities for materials research. These facilities, defined as those with initial cost of at least $5 million, include, among others, sources of synchrotron radiation and steady state and pulsed neutrons.

A committee of twenty-two members was formed within the NRC Commission on Physical Sciences, Mathematics, and Resources, representing the diverse disciplines that use facilities for major materials. The Committee's membership was also intended to mirror the differing research styles and the spectrum of organizations where the research is done. Scientific work with materials varies from that principally requiring laboratory-scale instrumentation to that dependent on the availability of major facilities that the Committee was asked to address. It is done by governmental, academic, and industrial scientists and engineers.

The Major Materials Facilities Committee first met late in January 1984 and three times thereafter. Four panels of the Committee were formed: three to consider and make recommendations to the Committee regarding needs for synchrotron radiation, neutron scattering, and other specialized materials research facilities; and a fourth to analyze the budgetary implications of various sets of priorities. During its tenure, the Committee, or one of its panels meeting separately, was informed of or heard detailed presentations on the status and promise of many of the U.S. major materials facilities falling within its charge. Further, the President's Science Advisor, the directors of several national laboratories, and senior research officials of several federal agencies met with the Committee. [A list of presentations to the Committee is in Appendix C.] Finally, the Committee had available to it recently completed and advance drafts of reports relating to its topic, done by the National Research Council, the Department of Energy, and other organizations. In all, this report is the result of more than 6 months of extremely intensive efforts by the Committee, its panels, and its staff.

In addition to the executive summary, the report contains three chapters. Chapter I describes the facilities, research styles, and research performers of materials research in the United States. It also offers a brief summary of the status of U.S. facilities vis-a-vis those of other countries. Chapter II outlines scientific and technological accomplishments using major materials facilities and suggests the likely direction of future research. In short, it presents the scientific and technological rationale for the recommendations in this report. Chapter III expands on the conclusions and recommendations given in the executive summary.

A continuing concern throughout the Committee's deliberations was the possible misinterpretation, even misuse, of its report. As is emphasized several times in the text that follows, the knowledge generated by materials research comes from diverse research styles and performers, each vital to the total effort and each complementary to the other. These varying styles must each be well supported, for the health of the total effort in materials research. To deny funding to smaller scale research to support major facilities is destructive. Therefore, the recommendations in this report should be read and interpreted for what they are: a statement as to priorities solely for major materials facilities. The Committee did not address, and this report does not imply, any judgments on the total spectrum of work embraced by materials research.

By the same token, additional panels should be convened to address other aspects of materials research and to review previous recommendations in light of new information. Such panels, by responding to specific aspects of materials research needs, can contribute to the long-range planning and to the setting of priorities for the materials research field.

The task before the Committee was difficult and painful. Its recommendations, and its omissions, would, if they were adopted, have a major effect on the future direction of materials research in the United States, on the institutions where major facilities are or may be based, and, likely, on the future competitive status of major segments of United States technology. That the Committee fully agreed to the need to recommend priorities testifies to the cosmopolitan views of its members; that reaching agreement on priorities was difficult testifies to their strong beliefs in the value of particular facilities.

The National Research Council is indebted to the members of the Committee for their patience, goodwill, and dedication to an arduous and trying task.

Dean E. Eastman
Frederick Seitz
Co-Chairmen, Major Materials
Facilities Committee

CONTENTS

PREFACE xi
EXECUTIVE SUMMARY 1
    Conclusions and Recommendations 3
    Recommended Priorities 3
I. MATERIALS RESEARCH: FACILITIES AND MODES 7
    Universities 7
    Federal Laboratories 10
    Industry 10
    Major Materials Facilities 11
II. MAJOR MATERIALS FACILITIES: SCIENCE AND TECHNOLOGY 17
    Synchrotron Radiation, Neutron Scattering, and Magnetic Fields 17
    Synchrotron Radiation Research: Past and Future 21
    Neutron Scattering Research: Past and Future 30
    Research with Magnet Facilities: Past and Future 37
    Advanced Technology Needs: Applications of New Facilities 40
III. CONCLUSIONS AND RECOMMENDATIONS 43
    Recommended Priorities 44
    Estimated Costs of the Recommendations 49
    Other Specialized Facilities Considered by the Committee 54

APPENDIXES

A. REPRINT: George H. Vineyard and L. M. Falicov, "National Facilities for Research in the Physics of Condensed Matter," Review of Scientific Instruments, Vol. 55, No. 4, 620-630, April 1984 57

B. REFERENCES AND RELATED LITERATURE 69

C. LIST OF PRESENTATIONS MADE TO THE MAJOR MATERIALS FACILITIES COMMITTEE (the complete presentations will appear in a supplement to this report) 73

D. PRESENTATIONS TO PANELS 77

EXECUTIVE SUMMARY

The science of condensed matter, or materials research, deals with the properties of solids and liquids and their interfaces. It is interdisciplinary, involving materials science, major areas of physics and chemistry, and the earth sciences, biology, and medicine. The understanding of the behavior and properties of materials undergirds every major technology; as a consequence, strength in materials research is essential to national capacities in advanced technology and, hence, to economic competitiveness.

Like all sciences, materials research depends on instruments, with these instruments ranging from laboratory size, such as mass spectrometers, to major national facilities, such as sources of synchrotron radiation and neutrons.

This report deals solely with major facilities. That was the Committee's charge. The facilities considered were those that are national in scope, with initial costs on the order of $5-10 million or more, intended primarily for research on materials. However, materials research done on a laboratory scale is equally vital to the future strength of U.S. materials research. Support for laboratory-scale science is complementary to, not competitive with, the support for major facilities recommended in this report.

The relatively high costs of major facilities for materials research dictate that priorities be established; and the Committee in this report recommends priorities for major new facilities and new capabilities at existing facilities, for materials research and related fields. The recommended priorities involve three types of facilities, providing synchrotron radiation, neutrons, and high magnetic fields.

Synchrotron radiation, produced when energetic electrons are deflected by a magnetic field, provides over a broad spectral range the most intense source of photons now available. Such radiation can be intensified further by orders of magnitude by using insertion devices--wigglers and undulators--that put a series of sharp bends in the electron trajectories. Synchrotron-produced photons interact strongly with atomic electrons, thus, offering a means of probing the details of the electronic structure of materials.

In contrast, neutrons, which are produced by nuclear reactions, interact most strongly with atomic nucleii. Neutrons are thus uniquely suited to the study of lattice dynamics and molecular configurations. In addition, since the neutron has a magnetic moment, neutron scattering offers a unique means of probing the magnetic properties of materials. The most effective use cold neutrons, which have very low velocities, requires that they be transported through special tubes, whose walls reflect those neutrons with minimum loss, to large experimental areas called guide halls.

High magnetic fields are essential to the study of a variety of technical and fundamental problems. In particular, high magnetic field facilities are essential to the development of improved superconductors and, in turn, make it possible to construct more efficient superconducting magnets capable of achieving still higher fields.

The Committee applied the following criteria in establishing its priorities:

- The importance of each facility for frontier research in materials, and consideration of research needs of other fields, including biology, chemistry, atomic and molecular physics, plasma physics, earth science, and medical science.
- The importance of each facility for applied research in areas of national priority; that is, economic competitiveness and security.
- The availability of other, less costly alternatives for accomplishing comparable scientific, technological, and educational goals.
- The contribution of each facility to a long-term national plan for such facilities, including considerations such as capital investment, operations costs, and technical feasibility.

Additional criteria that should be considered in evaluating proposals for new facilities include:

- Technical and scientific resources at the laboratory or university site, including schools or departments in related areas.
- Access and ease of use by extramural academic, industrial, or government laboratory investigators.
- Role of the facility relative to a new or strengthened mission of its home laboratory or university.
- Potential of each facility for training scientists and engineers.

Further, new facilities to be fully effective must be dedicated, that is, used exclusively for synchrotron radiation or neutron based research. Finally, to serve the entire community optimally, the geographic distribution of facilities should generally be taken into account.

CONCLUSIONS AND RECOMMENDATIONS

The Committee's recommended priorities for major facilities--both new facilities and new capabilities at existing ones--embody two prerequisites:

- That they are accompanied by expanded support of smaller materials research programs, including related instrumentation. Research on this scale continues to provide much of the fundamental new science in the field and to train a large fraction of our scientific and technical manpower.
- That resources must be provided to operate existing user facilities productively. In addition, the approved enhancements of major synchrotron radiation facilities at the Brookhaven National Laboratory, Stanford University, and the University of Wisconsin should be completed expeditiously, since it will require several years to more than a decade before the new facilities recommended in this report can contribute to the research effort of the United States.

RECOMMENDED PRIORITIES

The Committee's recommended priorities for the development and construction of facilities during the next decade include two categories:

- Major new facilities, and
- New capabilities at existing facilities.

These categories complement one another in function, time scale, and required resources. New capabilities at existing facilities are essential for scientific and technological needs in the next decade, while the long lead times needed to construct major new synchrotron radiation and neutron facilities require that we start now with the planning and design of such new facilities. They also require that we begin immediately to implement new capabilities at existing facilities. The Committee concludes that both categories are essential for the effective evolution of science and advanced technology in the United States in the next decade and beyond.

The Committee also recommends the convening of additional panels to address other important aspects of materials research.

Major New Facilities

The Committee's recommendations for the construction of major new facilities are listed below in order of priority.

1. A 6 GeV Synchrotron Radiation Facility. This would be designed to make optimum use of the new scientific and technological opportunities presented by insertion devices. These devices, by providing radiation having orders of magnitude greater brightness than currently available, will make it possible to expand on the seminal research using synchrotron radiation carried out in the past decade. A synchrotron radiation facility with a storage ring energy of about 6 GeV will offer both identifiable and unforseeable new opportunities for research throughout the electromagnetic spectrum. It is optimal for providing radiation from undulators at about 10 keV, where most x-ray research is done. For example, the brightness increase will make it possible to investigate the properties of more complex materials and smaller samples with increased spatial and energy resolution. Site-independent design should begin immediately, and the site selection and construction should commence as soon as possible. If construction were to begin, for example, in FY 87, operation is possible by FY 92.
2. An Advanced Steady State Neutron Facility. The goal is to achieve about ten times the flux of existing machines with a minimum requirement of five times the flux. There are two principal reasons for this recommendation. First, and most important, a high-flux source can be designed to optimize beam geometry and flux distribution, so as to yield greatly increased intensities for all experiments. An increase of about ten times the flux of existing machines is an aggressive but technologically feasible goal. Such a facility would ensure the United States a leading position in this field. This is especially important in the cold neutron range, where flux increases of an order of magnitude can be achieved, providing new capability, for example, for high-resolution spectroscopy and small-angle scattering studies. Second, a new source will be a timely replacement for one or more of our existing sources built in the 1960's. Site-independent design should begin immediately. However, because of safety requirements, the Committee does not expect construction to begin until about FY 89 with completion possibly by FY 96.
3. A 1 to 2 GeV Synchrotron Radiation Facility. This facility would be centered around insertion devices but optimized for the vacuum ultraviolet (VUV) and soft x-ray region. This facility furnishes additional scientific and technical opportunities for research in chemical physics, electron spectroscopy, and imaging techniques such as microscopy and holography.
4. A High-Intensity Pulsed Neutron Facility. Pulsed neutron sources offer new scientific capabilities, especially for investigations requiring higher energy, or greater than thermal, neutrons. Also, there are practical limits to the intensity that steady state reactors can provide. Thus, future improvements in neutron sources, beyond the second priority above, will probably come from alternative approaches, the most promising of which is based on pulsed neutron

sources. However, future action on the construction of a high-intensity pulsed source (about 10^{17} neutrons/cm^2-sec peak flux) should be based upon the results obtained with lower-intensity pulsed sources.

New Capabilities at Existing Facilities

Recent developments make it both practical and cost effective to adapt certain existing user facilities to new purposes by adding experimental halls, instruments, and modified sources. These additions provide an opportunity for new frontier science; they are not simply extensions of existing work.

The Committee's recommendations in order of priority for the addition of these new capabilities at existing user facilities are:

1. Centers for Cold Neutron Research. Guide halls and instrumentation for exploiting the only cold neutron sources in the U.S. located at the Brookhaven National Laboratory and at the National Bureau of Standards, should be developed in an orderly fashion.

There is no cold neutron guide hall in the United States, and such facilities are urgently needed to address the rapid expansion of neutron applications in materials science, chemistry, and biology. Many central problems in these sciences can only be solved using new instruments with cold neutron beams. These centers will enable U.S. scientists to be competitive in cold neutron research during the next decade; and they will provide new instrumentation concepts for developing future neutron scattering sources.

2. Insertion Devices on Existing Synchrotron Radiation Facilities. Insertion devices should be developed in an orderly fashion to exploit about six of the remaining straight sections of existing storage rings. The special characteristics of undulators as radiation sources should be emphasized, to use our existing capability most effectively.

Undulators on existing machines will be our premier synchrotron radiation source for the next 5 years. They will also provide valuable experience for the next generation of synchrotron radiation facilities which will also be based upon undulators. The construction of additional insertion devices, when approved, should follow the construction of new capabilities at synchrotron radiation facilities already included in the budgets for FY 85 and FY 86.

3. Experimental Hall and Instrumentation at the Los Alamos National Laboratory. An experimental hall and new instruments at the pulsed neutron source at the Los Alamos National Laboratory (LANL) would make the United States competitive in pulsed neutron research and would help guide the development of future pulsed sources.

The expected flux increase at this facility is an important opportunity to explore, at modest cost, the great promise of pulsed neutron science for spectroscopic and structural problems.

4. Upgrading of the National Magnet Laboratory. The need for timely development of pulsed magnetic field facilities and instrumentation enhancements at the National Magnet Laboratory has been demonstrated. This laboratory, the only major high magnetic field research facility in the United States provides a unique combination of high fields and low temperatures. Many advances in research depend on its continued development as a dedicated user facility.

5. Enriched Pulsed Neutron Targets. Enriched targets, by exploiting fission events to amplify the neutron flux, can more than double the available flux. The development and installation of enriched targets for use at pulsed neutron facilities would be cost effective.

Priorities 1 and 2 for major new facilities, when they are implemented, would serve as a centerpiece of this nation's future capability for synchrotron radiation and neutron based research. Thus, design and siting studies for a 6 GeV synchrotron radiation facility and for an advanced steady state neutron facility should begin immediately.

Because of the long lead time associated with an advanced steady state neutron facility, the immediate implementation of at least one instrumented cold neutron guide hall is necessary to provide forefront capability.

The basis for these conclusions is expanded upon in the body of the report. Chapter I outlines the characteristics of materials research at universities, at governmental and private laboratories, and in industry, including research styles, research organizational modes, instrumentation, and the role of national facilities. It also offers a brief summary of the status of U.S. facilities vis-a-vis those of other countries. Chapter II outlines scientific and technological accomplishments, using major materials facilities, and suggests the likely direction of future research. It presents the scientific and technological rationale for the recommendations in this report. The Committee's conclusions and recommended priorities for national facilities for materials research and related fields are given in Chapter III.

The Committee again emphasizes that, in response to its charge, its recommended priorities include only synchrotron radiation, neutron scattering, and high magnetic field facilities. Other meritorious materials research facilities were also discussed by the Committee. A number of these are briefly described in Chapters I and III.

I. MATERIALS RESEARCH: FACILITIES AND MODES

Materials research is by its nature interdisciplinary, historically calling on expertise from engineering, physics, earth sciences, and chemistry and, recently, extending to biology and medicine.

In this chapter, we briefly describe the diverse research styles and types of facilities, instrumentation requirements, organizations, and modes of materials research. This is intended to set the context for the focus of the report: major neutron, synchrotron radiation, and high magnetic field facilities, costing in excess of about $5 million. These are all are national user facilities, each serving a group or groups of users whose interests often extend beyond the traditional materials research community. This focus responds to the charge to the committee, as stated in the opening sentences of the Preface and the Executive Summary.

Universities, the federal government, and private corporations are all involved in materials research. In universities, it is done in the main in different disciplinary departments. Within the government, it is done within facilities operated for the U.S. Department of Energy by private contractors, such as the Oak Ridge National Laboratory, the in-house laboratories of the Department of Defense, such as the Naval Research Laboratory, and other laboratories such as the National Bureau of Standards. Numerous industrial laboratories are also involved in materials research, usually in an interdisciplinary mode, ranging in focus from fundamental work to development and manufacturing.

UNIVERSITIES

Much of the materials research in the United States is done in small university laboratories, consisting of a few researchers and a total instrumentation inventory of less than $1 million. Research on this scale continues to provide important, fundamental new science and to train a large fraction of our scientific and technical manpower.

Universities have a crucial role in materials research. They are a major source of new ideas and concepts that often take years to mature, time that industry often cannot commit. And they are the sole source of future materials scientists and engineers. Universities also operate special research facilities that are used by a broader research community.

Training new scientists and engineers for materials research is complicated by the needs of advanced technology for people who are broadly trained and fully conversant across the conventional disciplinary boundaries, such as, for example, condensed-matter physics and chemical engineering.

An important task for the universities is to develop stronger ties with industrial and governmental laboratories. Such cooperative programs stimulate new research, promote the exchange of new knowledge and technology, and help in thecontinuing education of mature technical personnel at industrial and governmental laboratories.

Materials Research Laboratories

The Materials Research Laboratory (MRL) program, supported by the National Science Foundation and the Department of Energy, is intended to stimulate interdisciplinary materials research within universities, of the sort not easily done under the traditional funding pattern of individual research projects. It emphasizes coherent, multi-investigator projects requiring collaboration among individuals in two or more materials-related disciplines. The MRL program has also emphasized the development of wellstaffed and well-equipped central research facilities, partly as mechanisms for stimulating collaboration. Finally, new projects can be quickly started with MRL funding including seed funds to assist both new faculty members and established faculty members with novel ideas or programs who wish to change research fields. MRL core support is not intended as a substitute for individual research project funding, but may properly catalyze significant new research initiatives. Several Materials Research Centers at universities are funded by the Department of Energy and by other agencies. A smaller kind of specialized program, the Materials Research Group, is currently under consideration by NSF.

Instrumentation for Materials Research*

The status of instrumentation in university research laboratories was examined in a 1971 study of the National Research Council (reference 23), commissioned by the National Science Foundation. At that time, a need for $200 million in new instrumentation was identified. Only a small fraction of the need was met at the time, leading to a more problematical situation now. Thus, in the intervening decade, the consumer price index rose by slightly more than a factor of three, while instrumentation costs inflated at almost twice that rate. The accumulated need is now at least $1 billion, and some estimates are considerably higher. The $1 billion estimate is what would be needed to bring university research laboratories up to modern standards and does not include the cost of major new facilities, such as reactors or accelerators. Results from a 1984 National Science Foundation instrumentation survey (reference 24) indicate that only 16 percent of current academic research equipment in the physical sciences could be characterized as "state of the art." Dealing with this crisis in university instrumentation is a matter of national urgency.

---

* While this discussion of instrumentation focuses on the needs of the universities, many of the same problems are faced by governmental laboratories engaged in materials research.

Small- and Large-Scale Instrumentation. Exacerbating the shortcomings in university instrumentation is the increasing need for new larger-scale instrumentation for small research groups, instrumentation that is expensive by traditional standards but modest by those of the national facilities. In some cases, the cost of such instrumentation, typically $250,000 to $1,000,000, will necessitate considerable sharing, usually with other investigators or groups at the same institution. Examples include electron microscopes, the new generations of high-powered or very fast lasers, equipment for studying specialized materials, such as molecular beam epitaxy or chemical vapor deposition apparatus, specialized environments such as "clean rooms," very high powered or pulsed magnets, and dedicated 32-bit superminicomputers.

The cost of equipping many experimental stations at large user laboratories is also in this category. For example, most of the beam lines at existing synchrotron radiation facilities now are financed by participating research teams from governmental, industry, and university laboratories. These groups provide their own funding for instrumenting ports to do particular kinds of experiments. It is expected that about half of the additional beam lines proposed in this report for the new and enhanced synchrotron radiation facilities will be funded by the research participants. Future neutron facilities may also be partly developed in this mode.

Large-Scale Computers. Over the past decade, a new and essentially different kind of instrument has been added to the increasingly complex instruments for experimental materials science: the large-scale computer, or supercomputer. Although simple properties of simple systems, such as the cohesive energies of elemental solids, can be calculated within about 10 hours with a 32-bit superminicomputer, calculations for more complex and interesting systems require vastly larger memory and increased computing speed. Greatly increased computing support, during the next 5 to 10 years, would qualitatively affect the usefulness of theory for the solution of materials problems.

Personnel

The need to fully use the facilities discussed here, coupled with the generally complex nature of modern materials research, implies a much more extensive use of technical and professional support staff in individual research groups than has been customary in the chemistry, physics, and materials science communities in universities. Biological scientists in universities are now well established in this mode of operation, as are many physical scientists in industrial and governmental laboratories.

FEDERAL LABORATORIES

The federally supported laboratories have widely diverse roles in U.S. materials science and technology, in keeping with the missions of their agencies. Thus, the national laboratories of the U.S. Department of Energy (DOE) conduct materials research related to the development of nuclear fission, fusion, and other energy sources, as well as to weapons. As do other federally supported laboratories, the DOE laboratories also operate special research facilities that are widely used by the broader scientific community. In fact, the special scientific or measurement capabilities, as well as the major facilities, of the federal laboratories, are the basis for their many cooperative research efforts with industry and universities.

The materials research and development activities of the laboratories of the Department of Defense (DOD) directly support general defense needs or particular weapon systems. Fundamental work in materials research centers on those activities areas inadequately addressed by the private sector or activities that may have an important long-range impact on the scientific or technological needs of future defense capabilities. Overall, the DOD laboratories can engage, when it is necessary, in all aspects of materials research and development, from fundamental concepts to providing prototypes. Finally, the direct role of the DOD in materials research is complemented by its indirect role in broadly supporting contract R&D at academic, industrial, and governmental laboratories of other agencies.

Other governmental departments and agencies also have major roles in materials research. For example, one of the central missions of the National Bureau of Standards, within the Department of Commerce, is research leading to new or improved measurement methods and standards and to basic understanding of the properties of materials needed by industry, universities, and government. The U.S. Geological Survey, within the Department of the Interior, has a major effort in basic and applied materials research related to the nation's mineral resources.

INDUSTRY

Condensed matter science is unusual in that a significant portion of basic research in the U.S. is performed in industry. This reflects the fact that condensed matter science supports advanced technologies in many areas of national priority, including those of information systems, energy, health, transportation, and national security. Basic industrial research is conducted in all sub-areas of condensed matter science using many modes, ranging from the individual researcher to research groups. Industrial researchers also make active use of national facilities and collaborate in these efforts with university and governmental researchers. Multidisciplinary materials research is often carried out effectively at the major U.S. industrial research laboratories.

In addition to playing a major role in basic materials research, industry also helps define the future materials needed to advance important key technologies. That, in turn, serves as a guide to research at university and governmental laboratories as well as at industry laboratories.

The largest materials research effort in the U.S. undoubtedly is the industrial research and development effort focused upon product lines. Because this effort often requires advanced applications of materials for specialized uses, it generally requires a fundamental understanding of materials. The availability of university-trained scientific and technical personnel is essential for this extensive industrial research and development. Collaboration by industry researchers, with scientists and engineers at both university and governmental laboratories, contributes substantially to technology transfer. Recently, specialized facilities, such as microelectronics-related facilities, have been created at universities to address both basic research and the technology needs in industry.

MAJOR MATERIALS FACILITIES

Within the above perspectives on the diversity and range of facilities and practioners of materials research, the Committee describes below the status of several major materials facilities in the United States. These facilities are more fully described in a recent review article (reference 22).

Synchrotron Radiation Facilities

The synchrotron radiation facilities in the United States today range from small, virtually in-house facilities to large user facilities. The Cornell High Energy Synchrotron Source (CHESS) is a laboratory using a 5.5 GeV storage ring parasitically. The six end stations serve about 250 users annually. The National Synchrotron Light Source (NSLS) at the Brookhaven National Laboratory has two storage rings, 0.75 and 2.5 GeV, dedicated to the use of synchrotron radiation. Approximately 58 end stations, including those in a current upgrade program, serve a growing user community, currently estimated at 400 scientists annually. The Synchrotron Radiation Center (SRC) at the University of Wisconsin, currently operates a 0.24 GeV storage ring and is commissioning a 0.75 to 1.0 GeV ring. The 20 beam lines on the latter serve an estimated 150 users annually. The Stanford Synchrotron Research Laboratory (SSRL), at the Stanford Linear Accelerator Center, uses a 3.5 GeV storage ring dedicated to synchrotron radiation part of the year and in a parasitic mode the rest of the year. Counting beam lines in a current upgrade program, the 19 end stations serve a user community of 300 scientists. In addition, one undulator beam line is to be built on a 15 GeV storage ring at the same site.

The Synchrotron Ultraviolet Radiation Facility (SURF), at the National Bureau of Standards, is a 0.24 GeV ring dedicated to synchrotron radiation use. Its 13 beam lines serve about 40 users annually. Expanded descriptions of these facilities and a definition and history of the user community, as well as its characteristics, can be found in two previous reports (references 5, 8).

Of the storage rings listed above, only three--two at NSLS and one at SRC--were designed to be sources of synchrotron radiation, and those three were all designed prior to a full recognition of the importance of insertion devices. Consequently, they were designed to emphasize the radiation from the bending magnets, with capabilities for the later addition of a limited number of insertion devices. (For a description of insertion devices, see Chapter II and references 5, 8, 18, 19, 20, 26.)

Foreign Synchrotron Radiation Facilities. Many synchrotron radiation facilities exist elsewhere, offering strong competition to U.S. scientists. These are extensively described in other reports (references 5, 8). The principal operating sources are in England (SRS), France (ACO, super ACO), West Germany (HASYLAB, BESSY), Japan (Photon Factory), and the USSR (VEPP-3, VEPP-4). There are other facilities in some of these countries, as well as in Italy and Sweden. Construction is under way for facilities in the People's Republic of China, and there are plans for facilities in Taiwan, India, and Brazil. None of the facilities mentioned above is more advanced than our newest facilities, NSLS and SRC. However, the European Science Foundation is planning to build a 5 to 6 GeV storage ring very similar to that proposed for the United States.

Neutron Scattering Facilities

There are, currently, active neutron scattering programs at five different national centers: Argonne (ANL), Brookhaven (BNL), Los Alamos (LANL), National Bureau of Standards (NBS), and Oak Ridge (ORNL). The BNL, NBS, and ORNL facilities center around steady state reactor sources, while ANL and LANL involve pulsed spallation sources. There are also reactor based neutron scattering programs at the University of Missouri, the Massachusetts Institute of Technology, and other universities. This section focuses on the national centers for neutron research.

The BNL facility centers around the 60 MW High Flux Beam Reactor (HFBR), which has a thermal flux of 1 X 10^{15} neutrons/cm^2-sec. It is equipped with eleven spectrometers and diffractometers, with two more under development. The NBS facility has nine end stations, with a tenth under development. A cold source has been installed on the BNL reactor, and funding has been provided for installation of a large volume cold source in the NBS reactor. The ORNL facility centers around the 100 MW High Flux Isotope Reactor (HFIR), which has a thermal flux of 1 X 10^{15} neutrons/cm^2-sec. It is equipped with nine scattering instruments, with a tenth under development. The instruments include a 30-meter small-angle scattering instrument that is funded by NSF as a national user facility. The ANL facility centers around a pulsed neutron source that produces bursts of neutrons with a peak thermal flux of 4 X 10^{14} neutrons/cm^2-sec at a 30 Hz repetition rate. It is now the most intense pulsed source in the world, equipped with eight instruments, with a cold moderator available for several beams. The LANL facility centers around a pulsed spallation source that, by 1986, will provide a peak thermal flux of about 1 X 10^{16} neutrons/cm^2-sec at 10 Hz. Six beam lines are now available, with two instruments operating in the user mode. Ten or more beam lines will ultimately be developed.

All of these centers have ancillary equipment, enabling one to study samples in varied environments with temperatures from 0.3K to 1800K, pressures up to 20 kbar, and magnetic fields up to 80 kG. There is extensive research by outside users at each center, with the individual center user programs varying from informal collaborations to a formal peer-reviewed process. In most cases, outside user experiments involve collaboration with in-house people.

Aside from the facilities described above, there are efforts at the various neutron centers to develop area detectors, multilayer polarizing monochromators, focusing collimators, and neutron choppers and polarizers, all of which are important for developing advanced instrumentation for reactor or pulsed sources. These efforts, in general, have a low-to-modest level of support and manpower compared with instrumentation projects in Europe, discussed below.

Foreign Neutron Scattering Facilities. This subsection offers a selective review of foreign neutron scattering facilities, concentrating on instrumentation developments particularly in Western Europe that have not been matched in the United States. An important key to the European success, especially at the Institut Laue Langevin (ILL), has been the development and use of cold neutron sources and associated guide halls to create instruments for ultra high-resolution and high-sensitivity spectroscopy. These currently provide energy resolutions as much as five orders of magnitude better than those available in the United States; they also enable studies of small-angle and medium-resolution diffraction and other new scientific applications. As already noted, there is only one cold neutron reactor source in the United States, at BNL, and another under development, at NBS.

The United States has no guide halls to improve the versatility and flexibility of cold or thermal neutron instruments. In contrast, 60 percent of the neutron scattering instruments at the ILL (reference 7) are located in a large guide hall, and a new guide hall and cold source are to be completed over the next 2 years. Also, there are major efforts at ILL to develop and construct focusing monochromators, polarizing devices, reflecting supermirrors, environmental control systems, dedicated instruments for diffraction surveys using neutron cameras, and more. Besides the ILL program, there is a new reactor center, called Orphee, at Saclay near Paris, with two hydrogen cold sources, which will ultimately commission over twenty new instruments for neutron scattering and fundamental physics research. Expanded guide halls with many new instruments are also under construction at the KFA Research Reactor in Julich and at the Berlin reactor. Finally, the Japanese government has approved funding for the complete modernization of the JAERI III Reactor at a cost of $150 million, including a replacement of the vessel, an upgraded fuel and beam tube arrangement, and installation of a large cold source and guide hall.

The total current operating expenditures for neutron scattering at research reactors in Western Europe is about $80 million per year, in FY 83 dollars, including associated reactor operation costs, roughly triple the U.S. effort. An order of magnitude difference emerges when one compares capital investment for new spectrometer development and construction efforts. The consequences of this investment gap over the past decade between European and U.S. research reactors are being felt increasingly in our inability to compete in many areas of new science involving such techniques as high-resolution neutron spectroscopy, small- and medium-angle diffraction, and diffuse scattering.

The current U.S. position in pulsed neutron research and development is better in relative terms with respect to foreign competitors than for steady state sources. For example, the Intense Pulsed Neutron Source (IPNS) at Argonne is presently the highest intensity facility in the world, and the Weapons Neutron Research/Proton Storage Ring (WNR/PSR) at Los Alamos is scheduled to provide, by 1987, an order of magnitude increase in intensity for pulsed neutron experiments.

However, developments abroad make current comparisons misleading. For example, the SNS advanced spallation source under construction at the Rutherford Laboratory in Britain, which is scheduled to be brought on line by the end of 1984, will have neutron intensities 2 to 3 times the current IPNS performance and will, by 1986, generate a peak thermal flux of 5×10^{15} neutrons/cm^2-sec at a 50 Hz repetition rate. That is roughly twice the total intensity of the scheduled WNR/PSR source. This facility will ultimately have a complement of at least 15 neutron scattering instruments. Moreover, the Japanese, who have developed a modest flux facility at Tsukuba with an impressive array of instruments, are also funding a planning and design study for a major new pulsed source, costing $100 million in FY 83 dollars, which would slightly exceed the characteristics of the SNS at the Rutherford Laboratory.

User Policy at Major Materials Facilities

Since major materials facilities are intended for a large community of scientists, it is very important that they be available to all qualified research investigators with meritorious proposals. A number of approaches have been used in the past to arrange participation, each having strengths and weaknesses. Some perspectives and generalizations from experiences to date are given below to help guide the formulation of future policies.

Criteria. There are several extant models of user policies for major neutron and synchrotron radiation facilities. In general, they satisfy the following generic criteria:

1. Experimental activities, except for construction and maintenance, whether they are initiated by research staff of the facility or by outside scientists, are presented and justified in written form. The proposals are reviewed before research is authorized and begun.
2. Committees reviewing proposals include a substantial fraction of scientists from outside the facility.
3. Priorities are established by the facility director based on ratings of the review committee and on scheduling considerations. The director has the discretion to provide for the insertion of experiments to exploit blocks of instrument time that are freed by unanticipated events.
4. Use of a facility is not restricted to U.S. scientists, but priority may be given to them in the event of equivalent proposals.
5. The time assigned for an experiment is designed to be adequate for the measurements, but extensive, repetitive, or confirmatory measurements may require the submission of additional proposals.
6. Some fraction of instrument time should be made available for use by the director at his or her discretion. This time can be used to extend assigned periods for current experiments, to permit preliminary experimentation in advance of a proposal, and for instrument development. Approximately 20 percent of instrument time is suggested for such purposes.
7. Users should be provided with an adequate level of technical support at the instrument so that they can safely and efficiently conduct experiments. Vacuum interlocks, shielding, and other safety devices should be controlled by facility management. The design of user facilities should make it impossible or difficult for any user at one port to affect the beam delivered to any other port.
8. The facility should provide a stock of standard test instruments, normal electronic and vacuum components, cryogenic fluids (liquid nitrogen and helium), data acquisition computer systems, commonly used gases, and some minimum storage space for user owned equipment.
9. It should be recognized that there are a range of user interactions. Some users will make very short-term and straightforward measurements, others will do long-term, interactive experiments in

which protocols and parameters are altered as the experiment proceeds. The different needs of these groups should be considered in designing facility user policy.

Participating Research Teams. A concept that has been used successfully in several major facilities is that of the participating research team, or PRT. This is a group of individuals who take communal responsibility for the design, construction, and operation of an instrument at an existing port. The PRT may also be responsible for organizing funding for the instrument. Industrial, university, and governmental groups have formed PRT's. It is a concept that appears to provide a reasonably successful approach to using facilities.

The principle is that, for a specified period--2 to 3 years, for example--the PRT has some 75 percent of the running time for that port, outsiders being allocated 25 percent. This has the advantage that the management of each instrument becomes much more flexible for members of the PRT, and more effective science may therefore be done. An important responsibility of the PRT's is to provide help for outside users. By augmenting the local staff in this manner, the entry barrier for naive users can be reduced. In some cases, PRT's are reviewed every 3 years for possible renewal; involvement with outside users is an important consideration in such renewals. A PRT is responsible for maintaining the instrument. If the PRT does not find its own outside users through collaborations, the facility director can assign an outsider to use the PRT's line during the open time.

Maximal use of a facility may involve a mixed mode operation in which some beam lines are operated by PRT's and some by the facility. The consequent flexibility of operation at the scientific level justifies the administrative complexity of such an arrangement.

Whatever the user policy, the experience to date indicates that it is important to keep the level of bureaucracy as low as possible, even if there is some loss of efficiency in using the instrumentation. This criterion tends to conflict with that of extensive peer review of lengthy proposals by potential users, so some balance is called for.

A mixed mode operation in which a facility has participating research teams and provides instruments seems an appropriate balance. It is not the intent of the Committee to spell out a rigid user policy for future major materials facilities. Any proposals for a new facility, however, should include a well-considered plan for utilization, taking into account the considerations mentioned above. The aim, of course, is to create user policies that permit the best science in an atmosphere of equal opportunity for different users.

II. MAJOR MATERIALS FACILITIES: SCIENCE AND TECHNOLOGY

Condensed-matter science, or materials research, deals with the diverse properties of solids and liquids and their interfaces. It is interdisciplinary, involving materials science, including metallurgy, ceramics, polymers; major subareas of physics and chemistry; as well as the earth sciences, biology, and medicine. Interest in materials research derives from fundamental science and technology. It is an intellectually stimulating area of science, as shown by the discoveries of fundamentally new phenomena, concepts, and states of matter during the past decade. Indeed, several recent Nobel prizes have been awarded for research in condensed-matter science.

Condensed-matter science supports advanced technologies in areas of national priority, including those of information systems, communication and computers, energy, health, transportation, and national security. Products of condensed-matter science, such as the transistor and the integrated circuit chip, have revolutionized our lives through their use in television, calculators, electronic watches, personal computers, appliances, autos, and innumerable other applications. In Table II.1, the Committee summarizes the connection between subareas of materials research using major facilities and technological applications.

SYNCHROTRON RADIATION, NEUTRON SCATTERING, AND MAGNETIC FIELDS

The spectroscopic analysis of matter involves bombardment with particles, such as neutrons or photons, with or without energy changes, or the use of high magnetic fields. The sensitivity that can be achieved is limited by the intensity of the radiation or the strength of the field.

Neutrons

The neutron is a unique probe that interacts weakly with atomic nuclei. The magnetic moment of the neutron makes it especially suited for examining magnetic properties of materials. By measuring changes in the

Table II.1. Connection Between Materials Research Subareas and Other Fields that Utilize Major Materials Facilities and Technological Applications of National Interest

	Information Systems (computers, communications, electronics)	Energy (fossil, nuclear, fusion, solar,...)	Health (Medical, Biotechnology, Environmental)	National Security	Transportation (ground, air, space)
Semiconductors	+	+	+	+	+
Metals and alloys	+	+	+	+	+
Insulators	+	+		+	+
Polymers	+	+	+	+	+
Ceramics	+	+		+	+
Magnetic Materials	+	+	+	+	+
Catalysts		+	+	+	+
Adsorbates		+	+	+	+
Lamellar (layered) materials	+	+		+	+
Composites		+	+	+	+
Biological molecules, macromolecules, and membranes			+		
Gaseous molecules and atoms	+	+	+	+	+
Plasmas (atoms, ions)		+	+	+	

---

* In addition to bulk materials, thin films, interfaces, and surfaces of several of the above materials are of major scientific and technological importance.

momentum and energy of neutrons scattered by matter, direct information can be obtained on the structure of matter as well as its states of excitation.

For example, neutrons slowed to relatively low velocities--"cold neutrons"--have been used to "look" at the shapes of molten polymers. The technique is based on the fact that hydrogen and its heavier isotope, deuterium, scatter neutrons differently. Polymers are prepared in which hydrogen atoms are replaced by deuterium; isotope substitution does not alter the molecular configuration. Thus, when two polymers--ordinary and deuterated--are then exposed to a beam of cold neutrons, the actual size and configuration of the polymer can be deduced by comparing the different forms of neutron scattering from the two polymers.

Increased emphasis on research using cold neutrons is dependent on the availability of "guide halls," which are large experimental areas in which high resolution neutron spectrometers can be placed. This is possible because of the development of "guide tubes," which allow the neutrons to be transported many meters to the guide hall without significant loss of intensity.

Neutron beams can be either continuous or pulsed. Continuous beams are obtained from nuclear reactors, using controlled nuclear fission of uranium surrounded by suitable neutron moderators and reflectors, such as D_2 and beryllium. Pulsed neutron beams are generally produced from short bursts of high energy protons or electrons from an accelerator impinging on a heavy metal target, such as uranium or tungsten, to generate bursts of very high energy neutrons. This target is surrounded by a moderator-reflector assembly that is analogous to, but generally smaller than, that in a reactor, so that relatively short bursts of thermal and fast neutrons are produced at rates of 10 to 100 pulses per second.

Synchrotron Radiation

Synchrotron radiation is a unique source of photons, by virtue of its high intensity, brightness, stability, and broad energy range, extending from the far infrared to the x-ray region and beyond. It is created when charged particles within an electron accelerator are deflected by a magnetic field. The intensity of the synchrotron radiation can be further increased with the use of insertion devices. The simplest of these is the wiggler magnet that puts a relatively sharp kink in the electron trajectory of the synchrotron, thus increasing the radiation from that point. A more sophisticated device called an undulator in effect puts in a series of kinks so arranged that the light from each adds up in phase, giving an enormous increase in the intensity that can be achieved. Although synchrotron radiation represents a drain of energy in an accelerator, it was eventually recognized to be a source of intense radiation for new classes of experiments, first in solid state physics and then in other sciences.

Measurement of the momenta and energy of synchrotron-produced photons, which interact strongly with electrons, provides information on structure and excitations. Such excitations range from molecular vibrations, measured in the infrared, to the ejection of electrons from the innermost electron shells of atoms by photons in the x-ray region of the spectrum.

Such capabilities are very important for many fields. For example, synchrotron radiation is a major tool in probing the geometry and electronic structures of surface and solid-solid interfaces. In particular, photons from synchrotron radiation are used for photoelectron spectroscopy, in which electrons are ejected and their energy and angular distribution then measured.

Magnetic Fields

High magnetic field research is important for the fundamental understanding of a broad range of materials properties. Scientific advances in such diverse areas as superconductivity, permanent magnet research, and semiconductor science, all benefit from research based on the availability of intense magnetic fields. The attainment of such fields is ultimately connected to useful applications, development and industrial commercialization. Each time a higher magnetic field strength is achieved, it is quickly exploited by the scientific community and is accompanied by a requirement for yet higher field strengths. This new demand often requires a combination of high fields and low temperatures, or the combination of high magnetic fields with ancillary measuring equipment such as precision optical systems.

Superconductivity is the research area most strongly linked to high magnetic fields. An understanding of superconductors, which could form the basis for new and improved high field magnets, depends upon experiments carried out in some of the highest available fields. Therefore, the availability of present-day high field facilities is closely linked to the development of future facilities. High magnetic fields are also essential for probing those fundamental properties of superconductors that can be used to test microscopic theories, including theories based on the concept of electron pairing.

Basic Principles And New Problems

Against this background, it should be recognized that a family of basic principles and techniques underpins the field of materials research. Some of these have already been well exploited and are well understood. For example, the existence of lattice vibrations of short wavelength in metals was settled decisively with the use of neutrons some 25 years ago. Likewise, the electron energy band dispersions of solids and surfaces have been determined directly using photoelectron spectroscopy. Extended X-Ray Absorption Fine Structure (EXAFS) has been employed extensively to determine site-specific atomic structure for parts-per-million impurity concentrations and adsorbates. However, the applications of x-ray and neutron scattering to biology and polymer science, as well as to other aspects of materials science, are just beginning.

Effective, increased use of such techniques for improved understanding of fundamental biological processes will require the establishment of additional mechanisms for bridging between physical and biomedical scientists.

As theoretical concepts and processes for synthesizing materials advance, new problems come to the fore. Many involve the acquisition of detailed information regarding structural and dynamic properties that can be provided with the techniques employing neutron scattering, synchrotron radiation, or strong magnetic fields. Although it is impossible to forecast exactly how these techniques will be used to solve such problems, the Committee can predict confidently that there will be new problems a decade from now that will be especially amenable to approach with the equipment available at major materials facilities. The value of having equipment with advanced capabilities available to solve as yet barely discernible problems should not be underestimated. To indicate the breadth of applicability of such facilities, a partial list of available techniques is summarized in Table II.2.

Many problems that are well defined now cannot be explored adequately because the appropriate instrumentation or facilities are not available in the United States. Examples include the determination of the dynamics of intercalate species in single crystals of intercalated graphite having semiconducting properties. This problem can be approached using neutron scattering, along with nondestructive determinations of the concentration of electronic impurities in the range of 0.1 ppm using an x-ray microprobe.

In the following sections we discuss areas of science in which new major materials facilities can be expected to make further important contributions. More extensive summaries are described elsewhere (references 1, 2, 5, 7, 8, 18, 20).

SYNCHROTRON RADIATION RESEARCH: PAST AND FUTURE

Research with synchrotron radiation began in the 1960's and has grown dramatically in the past decade. Whenever a synchrotron radiation facility offering an increase in brightness, typically by a factor of from 10 to 10,000, became available, new types of research became possible. Furthermore, experiments carried out with such new equipment have usually demonstrated how new science could be developed if still higher brightness was available.

Four Generations

We have gone through three generations of such increases in brightness; the fourth is at hand. The first was associated with synchrotron radiation from the bending magnets of storage rings built for particle or nuclear physics. The second came with the construction of new storage rings specifically intended to produce synchrotron radiation (reference 1). These are now in operation or soon will be. The third emerged with the realization that insertion devices, wigglers and undulators

TABLE II.2. Techniques Available at Synchrotron Radiation and Neutron Facilities

		Neutrons	Photons	
			X-ray	Soft X-ray and VUV
I.	Elastic scattering*			
	Bulk crystallography	x	x	
	Surface crystallography	x	x	
	Molecular cystallography	x	x	
	Small angle scattering	x	x	
	Polarized scattering	x		
	Magnetic scattering	x		
	Diffuse scattering	x	x	
II.	Quasielastic scattering			
	Diffusion	x		
	Reorientation	x		
	Critical dynamics	x		
III.	Spectroscopy and elemental analysis			
	Inelastic (E,k) scattering			
	- electrons		x	x
	- phonons	x		
	- magnons	x		
	Absorption, reflection, fluorescence		x	x
	Absorption spectroscopy			
	- EXAFS		x	x
	- SEXAFS		x	x
	- PHD		x	x
	Photoelectron spectroscopy			
	- core level		x	x
	- valence level		x	x
	- ARPES		x	x
	- yield spectroscopy		x	x
	Photon stimulated desorption			x
	Photo chemistry		x	x
	Activation analysis			
	- thermal neutron activation	x		
	- prompt γ-ray	x		
	- fast neutron activation	x		
	- nuclear track	x		
IV.	Imaging and microscopy			
	Microscopy			x
	Microprobe		x	x
	Depth profiling	x	x	
	Topography	x	x	

TABLE II.2 (continued)

	Neutrons	Photons	
		X-ray	Soft X-ray and VUV
IV. Imaging and microscopy (continued)			
Lithography			x
Interferometry	x	x	
Radiography	x	x	
Autoradiography	x		
Holography			x
V. Radiation effects			
Radiation damage	x	x	x
Isotope production	x		
Transmutation doping	x		

---

* Many of the elastic and inelastic scattering techniques can be time resolved and/or spatially resolved with increased resolution and usefulness as the brightnesses of future sources are increased.

(see references 5, 8, 17, 18, 19), would enhance the intensity of synchrotron radiation. These devices have been, and are being, added to the present generation of storage rings, although not yet to the maximum possible degree. Unfortunately, the appreciation of the role insertion devices could play came too late to influence in any major way the design and construction of our present generation of storage rings.

The fourth generation of synchrotron radiation facilities, now technologically possible, involves the construction of new storage rings designed to maximize the brightness of the radiation from insertion devices. Such rings offer brightness increases by factors of from 50 to more than 100 over the best synchrotron radiation sources we have today or that we can achieve by adding new insertion devices to existing facilities. No dedicated facility that can produce undulator quality radiation in the x-ray region exists at present. Using the orders of magnitude increase in brightness that will be achieved with a new 6 GeV facility, we will be able to conduct entirely new types of experiments, some of which will open up major new research areas.

Synchrotron radiation has already contributed to many aspects of materials science as well as to other fields. Some of the more important contributions are outlined below. More extensive descriptions may be found in references 5, 8, 18, and 20, and in the references therein.

The simplest experiment, and one of great importance, centers about the measurement of photoabsorption by atoms, molecules, and solids. The continuum of synchrotron radiation allows easy access to the core levels of many atoms and has revealed a variety of many-body phenomena, including giant collective resonances, so-called Fano (interference) line shapes, "missing" spectral lines, and the "spike" shape of some absorption edges in metals. These have contributed to a better understanding of many-body effects in both atoms and solids.

At energies above the absorption edges in solids, the extended x-ray absorption fine structure (EXAFS), which is produced by interference effects in the scattering of the ejected core electron, gives precise information concerning the local geometry of the absorbing atom. When increased brightness is available, the EXAFS technique can be extended to detect elements in bulk samples and submonolayer adsorbates on surfaces that are present in concentrations of parts per million. EXAFS gives site-specific, geometrical information regarding atoms in samples of many types, such as coal, alloys, catalysts, and biological molecules. In most cases, the structural information obtained with the EXAFS technique was unattainable previously. Examples include geometrical information concerning the active site of the important nitrogen-fixing enzyme, nitrogenase; information relative to the active sites of important catalysts; structural parameters of impurities in coal and oil that make processing difficult; and studies of the role of impurities in determining important mechanical properties of materials.

Photoemission spectroscopy is widely employed at synchrotron radiation facilities. It provides independent information on initial and final electron states. Moreover, the anisotropy exhibited by atomic and molecular photoemission spectra gives information concerning atomic wave functions that is different from that obtained from absorption spectra.

Photoemission from molecules exhibits shape-dependent resonances that are studied in the gas phase and then used to determine the orientation of molecules on surfaces. The continuum of synchrotron radiation makes possible various forms of so called "yield spectroscopy," in which the absorption of photons is signalled by secondary events. In this way, one can, for example, selectively examine absorption in the region of a surface by monitoring the yield of Auger electrons. Similarly, one can determine the onset of bulk absorption by monitoring the emission of characteristic x-rays. Brighter synchrotron radiation sources have permitted angle-resolved photoemission experiments that give electronic band structure, including symmetry, directly from the data. These experiments yield fundamental energy band information for solids, surfaces, and adsorbates, and thereby provide the basis for a more complete understanding the electronic properties of matter.

While EXAFS and photoemission spectroscopies have been pursued since the advent of x-ray and VUV synchrotron radiation based research, x-ray scattering and direct imaging technologies are just beginning to be carried out with the newest generation of insertion devices and storage rings. In spite of the limited time in which they have been available for exploration, these facilities have already shown that they can be used to obtain significant results. This gives us confidence that research based on synchrotron radiation will benefit dramatically from the next generation of facilities employing insertion devices. The scattering of x-rays by monolayer adsorbates and freely suspended thin films that are two monolayers thick has already been successfully demonstrated. In addition to opening the techniques of x-ray crystallography to the world of surfaces, thin films, and interfaces, synchrotron radiation has permitted exploration of the scientifically important phenomena associated with two-dimensional phase transitions.

The increase in intensity offered by the newest storage rings has enabled the study of bulk crystals that are as small as 1 μm^3 in size, thus permitting the determination of the structure of many important materials, such as zeolites, that can only be grown in the form of very small crystals at present. The use of anomalous x-ray scattering promises to help solve the difficult problem of determining scattering phases that has plagued crystallographic studies of important large macromolecular systems. The pulsed nature of synchrotron radiation has been used successfully to study the technologically important process of laser annealing of silicon as well as the scientifically important problem of muscle action in animals. The initial experiments in which synchrotron radiation is used for angiography have shown real promise of improving this medically important diagnostic procedure dramatically (reference 8).

Summing up, the first three generations of synchrotron radiation have already provided us with a revolution in the capabilities for using photoemission and EXAFS techniques and have demonstrated great promise for employing scattering and imaging to advance many areas of science and technology. Insertion devices, particularly undulators, will advance the areas approachable with the use of photoemission and EXAFS techniques further and provide dramatic new opportunities for scattering and imaging.

The topics described above indicate what can be done with the newest sources of synchrotron radiation. More important are the even more complex research problems that can be undertaken with new storage rings that are designed specifically to use insertion devices. Examples are given below.

Condensed-Matter Physics

A major fraction of research using synchrotron radiation, both x-ray and soft x-ray, has involved the field of condensed-matter physics. There is a large number of new applications that cannot be addressed because of limitations of sources or instrumentation, or both.

Photoemission Spectroscopy. Photoemission spectroscopy is the primary technique for studying the electronic structure of solids, surfaces, adsorbates, and interfaces. On the basis of experiments being carried out at the new synchrotron radiation facilities, we can foresee what can be done with yet brighter sources. Angle-resolved photoemission provides understanding of the electronic band structure, including the band structure of the surface. The sample may be a crystal or an ordered overlayer. The resolution of angular and energy distributions has been increased with sources of higher brightness and have revealed new structures. Additional resolution is mandatory for the study of any material with a large unit cell, either in the interior or on reconstructed surfaces. Recently, measurements of spin-polarized photoemission have been carried out with synchrotron radiation. When combined with angle resolution, this procedure allows determination of the band structure of magnetic materials, including the spin labels for the bands. This is a technically difficult experiment. In particular, polarization detectors are notoriously inefficient. Brighter sources are mandatory if this technique is to be used widely.

At higher photon energies, one enters the region of x-ray photoemission in which the binding energies of core levels and the density of states for the valence electrons may be probed. Commercial equipment for this type of measurement with a resolution of approximately 0.5 eV at fixed photon energies is available. A synchrotron radiation source of the next generation would offer both higher resolution and higher sensitivity than anything possible today, thereby improving the utility of this already useful spectroscopy. Of perhaps greater significance is the extension of photoemission spectroscopy to procedures providing time and space resolution. This would make it possible to study surface reactions and to carry out microprobe studies of photoemission.

Surface Science. Other techniques for the study of surfaces also are benefitting from higher brightness sources. One is surface EXAFS, in which an absorbed x-ray excites a surface atom or molecule and a fluorescent x-ray or an Auger electron is then detected. The spectra give precise geometrical information on the location of the surface species. Photoelectron diffraction gives similar information. Both these techniques provide gains in surface sensitivity as the source brightness increases, and allow the study of surface species at ever great dilution. Finally, the new areas of photon-stimulated desorption of species from the surface requires sources of higher brightness. Both neutral and charged atoms and molecules, in their ground and excited states, can desorb from surfaces during photoabsorption. This may be the most site-specific surface phenomenon known. The photon flux used must be high because of the possibly small number of desorption sites and the low probability of release.

X-ray Scattering. X-ray sources of higher brightness are ushering in a new era in x-ray scattering. One can now work with surfaces, thin overlayers, and even freely suspended membranes. The crystallography of reconstructed surfaces can be determined, as can that of monolayer adsorbates. Thus, the crystallographic technique responsible for determining most of the known bulk structures can be extended to surfaces and thin films with insertion devices. This can be done as a function of temperature, to follow the structure and dynamics of quasi-two-dimensional melting. In fact, the study of phase transitions in two dimensions is providing important tests of theories of the behavior of the two-dimensional world of surfaces and thin films. Magnetic x-ray diffraction has been observed recently on the 54 pole wiggler at Stanford and promises to be comparatively routine when the brightest available x-ray wiggler sources can be used. Magnetic diffraction can provide much information concerning the magnetic structures of solids when an x-ray undulator on a 6 GeV source is available, and thus will complement traditional neutron studies, especially for materials for which only small samples are available. In some cases, surface magnetism may also be studied.

Inelastic X-ray Scattering. One field almost completely neglected in the first three phases of the evolution of synchrotron radiation has been inelastic x-ray scattering as related to the dynamic properties of the system being studied. The brightness of the radiation is most important for such research. Inelastic scattering of x-rays can, in principle, be used to probe both the electronic properties, such as those of plasmons, as well as collective atomic properties, such as lattice vibrations. However, achieving the 10^{-2} to 10^{-3} eV energy resolution needed will require the brightness provided by insertion devices and by major new instrumentation.

Atomic and Molecular Physics and Chemistry

Gas-phase photoemission has contributed extensively to our knowledge of atoms and molecules. Early studies emphasized the "static" study of excited states, the decay channels being inferred from line shapes. As the brightness of sources increased, the decay products, such as ions, electrons, and photons, could be detected. Finally, coincidence experiments began to be carried out, leading to more precise information regarding the nature of the excited states. Gas-phase experiments always require high brightness sources, for the sample is necessarily dilute.

The next-generation sources will permit several new classes of experiments. We already can work with gases at high enough resolution to excite single vibronic levels in molecules. These excited states can then be probed by high-resolution laser-spectroscopic techniques. Moreover, when source brightness becomes adequate, a molecule in an excited state can be made to interact with another molecule, bringing in an era of state-to-state photochemistry. These experiments are not possible with present sources because none have adequate brightness. Moreover, the time structure is not favorable.

The next-generation source will have pulse lengths shorter by a factor of about five relative to those now available. Such time structure will permit fluorescence spectroscopy from excited states on a time scale of a few picoseconds--shorter than the radiation pulse itself. This capability will, for example, make it possible to determine structural and dynamic properties of large molecules in solution and to study atomic and molecular reactions on surfaces. It will also be possible to use molecular beam techniques.

Biology and Medicine

EXAFS and x-ray crystallography involving synchrotron radiation have been applied to biological systems in the past. EXAFS has been useful for obtaining detailed information on large biomolecules such as hemoglobin. It is especially useful for molecules with a functionally important minority constituent, such as a metal atom in an enzyme. With increasing source brightness, it is possible to work with larger molecules having fewer active elements per unit volume. Time-dependent studies in which the structural response of the active site in the molecule to a chemical perturbation is determined become possible. Time-dependent x-ray absorption spectroscopy has already been used to follow the Fe absorption edge as the iron in myoglobin recombines with CO after laser-induced flash photolysis of carboxymyoglobin (references 25, 26). This was done on a 300 sec time scale with an existing storage ring. Better time resolution is possible, but EXAFS measurements on such a time scale await a source with higher brightness.

In studying x-ray damage to biological molecules and crystals, it has been found recently that the reciprocity law breaks down, and less damage results if the radiation dose is delivered at high rates for a short time. Therefore, higher-brightness sources offer the opportunity to work with smaller crystals, including those of molecules difficult to crystallize. They also make it possible to collect more data before samples become so badly damaged as to impair resolution.

Element-specific imaging represents the principal foreseeable application of synchrotron radiation to medicine. One form of coronary angiography used today involves the imaging of the coronary arteries in real time by K-edge absorption of iodine which is added to the blood. The classical technique is invasive, and provides relatively low resolution. In-vivo angiographic studies of animal hearts with synchrotron radiation are noninvasive, fast, and provide higher resolution. Studies on human hearts are planned and, if they are successful, should provide novel approaches to studies of atherosclerosis and, eventually, to clinical applications. A high-field wiggler would represent the only foreseeable source for such work with present machines, but bending-magnet radiation from a 6 GeV ring could facilitate applications of this technique.

Earth Sciences

The earth sciences provide opportunities for the application of synchrotron radiation in connection with microprobe analysis. Such analysis is now carried out with electron microprobes. Synchrotron radiation can also be used in x-ray diffraction studies at high pressures. Higher brightness than is now available will benefit such research.

Imaging and X-ray Microscopy

There are several methods for achieving element-specific imaging, all at a relatively primitive stage of development. These include microprobe analysis, microscopy with zone-plates, and contact "lithography." As source brightness grows and the coherence of the radiation from soft x-ray undulators increases, microscopic holography and soft x-ray diffraction will become feasible. Both processes promise to give three-dimensional images of microscopic biological elements with a spatial resolution down to about 50 Angstroms. Available new sources will allow demonstrations of these techniques, which can be applied to study phenomena within a single cell. An undulator on a next-generation storage ring will make it possible to carry out useful and wide-ranging studies on such systems, employing radiation that "sees" only one element at a time.

Electron microscopy cannot be applied readily to living cells. However, holographic imaging techniques may make it possible to work with living cells, or at least with cells that have been processed less than is now the norm in electron microscopy. The imaging can be carried out on a millisecond time scale and with submicron resolution. The source needed for such imaging, an undulator on a 1 to 2 GeV next-generation storage ring, will have coherence properties similar to those believed achievable with VUV and soft x-ray harmonics of visible and UV lasers. In fact, at shorter wavelengths, the undulator should provide higher average power than laser based sources (reference 27).

The foregoing selective examples show that synchrotron radiation is used for many purposes by scientists from a variety of disciplines. Research groups are combining the use of synchrotron radiation with other techniques, such as molecular beam epitaxy, pulsed lasers, and electron energy loss spectroscopy.

The versatility and power of research based on the characteristics of synchrotron radiation have emerged in the past 15 years. With the new capability provided by insertion devices, primarily undulators, the future impact of these devices will be even more profound.

NEUTRON SCATTERING RESEARCH: PAST AND FUTURE

Worldwide neutron scattering facilities and research applications have grown dramatically during the past decade. The most notable example is the emergence of the British/French/German center at the Institut Laue Langevin at Grenoble. But the Grenoble facility is only part of a major transformation of the field throughout Western Europe and more recently in the United States and Japan.

A New Generation Of Instruments: Europe And The United States

Over the past 25 years, the unique characteristics of the neutron as a probe of condensed matter has transformed much of our fundamental understanding of the physics and chemistry of materials. In keeping with this, a new generation of cold and thermal neutron instruments has been developed during the last decade, particularly in Europe. These have extended the wavevector range and energy resolution for neutron experiments by orders of magnitude. And they have, in turn, made possible new research in physics and chemistry and greatly expanded the applications of neutron scattering to new areas--materials science, polymers, and biology. Thus, the neutron scattering community in Europe has tripled in the past decade, and, more recently, the neutron scattering community in the United States has nearly doubled. This growth has also been stimulated by the emergence of higher-intensity pulsed neutron sources which by providing higher neutron energies have created new opportunities for neutron scattering research (reference 7).

The emphasis at current steady state reactor centers in the United States has been primarily on forefront research rather than on the development of instrumentation. This has been dictated, in part, by the U.S. neutron funding profile. By necessity, and in contrast, the pulsed source programs at Argonne and Los Alamos have emphasized development of pulsed source instrumentation and techniques, although important research has also been accomplished there.

Early neutron scattering research focused primarily on the exploration of basic issues in condensed-matter science. These issues included phonon and magnon dispersion relations, the structure of hydrogenous materials, crystallographic and magnetic structures in simple solids, and phase transitions in model systems. In the past decade, the range of systems under examination has broadened considerably, and the scientific issues have often become much subtler. Neutron scattering has thus become an essential tool, providing unique structural and dynamical information central to the elucidation of the physics, chemistry, and other attributes of systems that are typically of interest to very broad communities. This change in character is evident in the outstanding accomplishments involving the use of neutrons in the last decade at major centers around the world.

These accomplishments include elucidation of (a) the structures and transitions in magnetic superconductors, (b) the physics of disordered magnets including metallic glasses, percolating alloys, spin glasses, and random field magnets, (c) the structures and excitations of incommensurate systems, especially those involving one-dimensional mass and charge density waves, (d) tunneling modes in chemical systems, including deuterated solid methane and hydrogen trapped by impurities in metals, (e) stoichiometric rearrangement and diffusion mechanisms in fast ion conductors, (f) early stage nucleation of voids in metals, (g) single polymer chain configurations in bulk polymers as well as composite polymer materials, (h) the spatial organization of macromolecular assemblies such as ribosomes, and (i) the location and exchange of hydrogen in proteins.

Finally, there have been important contributions to basic particle physics, including the determination of an upper limit on the electric dipole moment of the neutron, an upper limit on the occurrence of nonlinear terms in the Schrödinger equation and limitations on the incorporation of gravity in the Schrödinger equation. In all of these cases, neutrons have played an essential role.

In spite of major contributions to these and other impressive accomplishments, the current state of the U.S. neutron facilities is unsatisfactory. The broadening of the scientific base of neutron scattering necessitates the development of new capabilities at existing facilities with a new generation of instrumentation. Further, by the mid-1990's our existing reactor sources will be 25 to 30 years old, so that their long-term viability becomes a serious issue. In addition, many experiments of current interest turn out to be signal- or resolution-limited, so that greatly increased fluxes are required. This can be achieved by developing a new steady state reactor and a new pulsed spallation source.

Against the above summary of past accomplishments, the Committee describes areas of materials research and other fields in which neutrons can be expected to make important future contributions if advanced instrumentation and new facilities are developed in the United States.

Condensed-Matter Physics

A major fraction of neutron scattering research traditionally has been directed toward condensed-matter physics. Concomitantly, there is a continuous stream of interesting and important physics problems for which neutrons provide essential information. There are, however, a quite large number of problems in condensed-matter physics of immediate importance that cannot currently be addressed in the United States because of limitations on instrumentation or flux. This class of problems is discussed below with emphasis on four research areas.

First, as a result of rapid progress in the techniques of mateials fabrication, a remarkable variety of lamellar materials can be synthesized. In all of these, there are important structural and lattice dynamical questions that often can be addressed only with the use of neutron scattering. Examples include artificial multilayer materials such as $GaAs/GaAl_xAs_{1-x}$, and CuNi. High-resolution studies of superlattice effects in the phonon dispersion relations are surely needed. Other important low-dimensional systems include graphite intercalation compounds of which very high quality but rather small (about $0.5\ mm^3$) single crystals have recently been produced, and also hexatic smectic liquid crystals. Studies of in-plane dynamics of the intercalates and of excitations in hexatic phases would yield fundamentally new results. A related and rapidly-growing area of research centers about the determination of the structure and dynamics of adsorbed species of molecules, especially hydrocarbons on high surface area substrates. All such studies would require high resolution and a copious flux of cold neutrons.

Second, in studying highly disordered magnets involving competing interactions, such as spin glasses and random field magnets, it has been found that important new effects occur in the time domain; for example, the system gradually freezes into a metastable state with decreasing temperature. Moreover, pronounced hysteresis effects that depend on the prior history of the sample are observed. This class of problems, which promises to grow in importance over the next decade, requires use of the very high energy resolution provided by the spin-echo technique.

A third new area of materials research relates to the study of nonequilibrium phenomena such as spinodal decomposition in supersatured alloys and turbulent flow in anisotropic liquids. The advent of wide angle position-sensitive detectors and modern data acquisition systems provides important new opportunities for such studies. Using a next-generation reactor source, one may expect to collect complete powder diffraction or small-angle scattering patterns with reasonable statistical accuracy for periods of time between 0.01 and 0.1 sec. This will allow probing the early time behavior of such systems.

A fourth area of research that has always been severely limited by both flux and instrumentation is the scattering of polarized neutrons. Polarized neutron techniques allow separating magnetic and nuclear scattering as well as coherent scattering and incoherent scattering arising from nuclear spins. An order of magnitude increase in flux, with improved polarizers for neutrons of short wavelength, would make many new experiments possible. Examples include studies of the excitations in magnets above the thermal transition temperature, elucidation of the spin dynamics in rare earth materials with mixed valences, separation of the magnetic scattering in spin glasses, and studies of magnetic defects in antiferromagnets.

There are, of course, always many important materials where, in spite of the best efforts of crystal growers, small sample size limits or prevents the full range of useful neutron experiments. Examples include Nb_3Sn, Nb_3Sb, $MEM(TCNQ)_2$, $ErRh_4B_4$, as well as others mentioned above. An order of magnitude increase in flux would bring many such problems into reach.

Finally, the increased neutron flux in the epithermal range will enable access to important new information on high-energy magnetic excitations in transition metals, actinide compounds, rare earth metals, and intermetallic compounds. Experiments involving the determination of the single particle momentum distribution in He^4 and He^3 as well as other light atom systems can also be anticipated.

Materials Science

Polymer and Colloid Science. The availability of small-angle neutron scattering (SANS) facilities has led to revolutionary advances in polymer science over the past decade. As indicated earlier, the substitution of deuterium for hydrogen makes it possible to extract information concerning the global molecular geometry of polymer molecules in the presence of high concentrations of other polymer molecules having the same chemical structure but differing isotopic compositions. There are at present no other experimental methods for making such measurements. Results have stimulated significant advances in understanding that, in turn, have led to new experiments. These SANS experiments have been carried out primarily on an instrumented cold neutron guide at Grenoble, although useful work has been achieved at new U.S. facilities. Important accomplishments include measurements of the conformation of single molecules in dilute and concentrated solutions and in amorphous bulk polymers. The state of miscibility of polymer blends and the state of aggregation of polymeric superstructures can also be characterized.

Extensive exploration of molecular interactions and phase diagrams over a range of temperature, concentration, and pressure will be required in the future. Those experiments will be dependent on greatly increased fluxes to achieve realistic data collection times. There is also a compelling need for studies of the dynamics of polymeric systems in real time--including phase transformation rates, deformation rates, annealing, and conformational changes. Measurements at lower wave vectors (q) are also needed to enable one to look at progressively larger polymeric molecules. Such new applications require modern SANS instruments located on cold source guide tubes with copious fluxes.

So far, only a limited number of low-energy inelastic scattering experiments have been reported in polymers. Here one is especially interested in low frequency motion in which long sections of the polymer molecule move in concert. Real advances require the development of spin-echo spectrometers, which also incorporate high-q resolution, along with back-reflection spectrometry having high-energy resolution. Quasi-elastic neutron scattering instruments covering an extended q range, from 0.01 to 2 Angstroms^{-1}, could, for example, provide an integrated understanding of the high-frequency motions that determine the chemical and electrical properties of polymers, and the low-frequency motions that dominate their mechanical and transport properties.

Metals, Alloys, Ceramics. The start-up of the high-flux, SANS instrument at Grenoble in the 1970's, along with earlier ground-breaking work at Jülich and Saclay, marked a turning point in the use of neutrons for studying structural and related problems in metals and alloys. These instruments made it possible to examine heterogeneities in bulk samples at small wave-vectors without multiple scattering. Important failure mechanisms in these materials are associated with the formation of small voids, often located at grain boundaries. These include radiation damage, hydrogen charging effects, high temperature fatigue, and creep. In the past, the small size of these pores and their low fractional volume made it difficult, if not impossible to obtain statistical information or to follow the growth and linkage leading to failure. Such studies are vital to test competing theories in these areas.

Another important use of SANS has occurred in the study of clustering and precipitation phenomena in alloys as well as in the investigation of internal oxidation. Here, again, important tests of theory, such as scaling laws, are occurring. Activities by U.S. scientists in this growing field which uses SANS facilities recently developed in this country, as well as the Grenoble instrument in Europe when available, to obtain additional sensitivity or resolution, are already making major contributions.

In spite of the progress that has already been made, the application of SANS to the study of microstructure and distributed damage in real engineering materials is at an early stage. There is a need to investigate the formation of voids and precipitates in steel and other structural alloys from a very early stage of development, emphasizing size and volume fraction. The exploitation of this and other major opportunities in the next decade will require the development in the United States of much higher intensities of neutrons of long wavelength, along with more efficient and effective collimation and area detection systems.

The attainment of much higher intensity SANS instruments will also permit the kinetics of processes such as precipitation, phase decomposition, and grain coarsening to be followed in real time, on a scale of about 0.1 sec or greater, under realistic conditions of temperature and stress. Higher sensitivity and resolution, as well as longer neutron wavelengths, will be needed to test models of damage accumulation that lead to failure of materials and of structures. Such capabilities will also be important for new areas, making possible, for example, in-situ studies of densification of ceramics at various stages of processing.

Other recent advances include the rapid development of high-resolution powder diffraction equipment at pulsed neutron and reactor sources. This not only permits the determination of the structure of materials such as complex ceramics and catalysts, which cannot be obtained in single crystal form, but also makes possible the study of residual and interaction stresses as a function of depth in metals and multiphase materials. Energy-dispersive pulsed source techniques have proven to be particularly useful in many of these studies. It is clear that such investigations will increase in importance in the next decade, particularly as much higher neutron intensities become available, allowing the stresses in smaller-volume elements in structural materials, and more complex structures, to be probed.

Chemistry

The most exciting opportunities for applying neutron scattering to condensed-matter chemistry in the next decade will require the development of instrumentation with very high resolution and high sensitivity for both elastic and inelastic scattering. In dynamic studies, this is particularly true for low energy cold neutron spectroscopy (0 to 20 meV) and quasi-elastic scattering, in which the use of neutrons provides unique information relative to other approaches. There is a growing interest in fundamental studies of rotational processes and interactions, tunneling phenomena, and ionic and molecular diffusion mechanisms in solids, as well as of molecular species bound in homogeneous and heterogeneous chemical media. The study of the dynamics of such systems on an atomic and molecular scale is of great importance, for example, in gaining understanding of the behavior and activity of catalysts and chemical absorbents, as well as of intercalated and layered materials. The studies will require energy resolutions between 0.1 μV and 0.1 meV, depending on the dynamic modes or processes being investigated.

Future applications of high-energy neutrons to determine vibrational spectra using pulsed or reactor sources will require considerably higher resolution as well as spectral measurements for variable wave-vector transfers. Experiments carried out under these conditions require much higher neutron fluxes to allow accurate measurements of line shapes and spectral intensities. This will, in turn, be necessary to test dynamic models of molecules bound in chemical systems. Moreover, many of the future applications of neutron scattering in chemistry will involve the measurement of high-resolution difference spectra, in which the signal from the species of interest is small in comparison with that from the surrounding medium. This small signal, coupled with the often small sample sizes, will accentuate the need for higher neutron intensities and new instruments. Measurement of difference spectra will make it possible, for example, to study the bonding, diffusion, and interaction of molecular species adsorbed in supported catalysts, as a function of the size of the catalyzing metal particles. Systematic studies using different catalysts, supporting substrates, and impurities are also of great interest.

In chemical crystallography, one of the requirements for neutron research in the next decade will be the extension of powder diffraction studies to ever higher resolution, so that more complex structures can be determined under wide ranges of temperature and pressure, for example, in ionic conductors, ceramics, catalysts, and even organic solids. High-resolution instruments will also be required to evaluate the details of disorder in complex stoichiometric and nonstoichiometric materials. For example, such new instruments will aid in the determination of the effect of incommensurate arrangements of oxygen and metal atoms in ceramics on the chemistry of these materials, such as titanates and niobates. In addition, studies of small single crystals, less than about 1 mm^3, of many new materials, including ceramics and inorganic complexes, will be required. Finally, there is a growing interest in real time, in-situ studies of atomic rearrangements occurring during solid state chemical reactions. All of these emerging applications require higher-intensity beams and greatly extended use of high-efficiency detectors and multidetector analyzers.

In the area of molecular liquids, the investigation of the relationships in dynamical behaviors of complex solutions, colloids, and micellar systems by small-angle neutron scattering and inelastic scattering will require high-resolution instruments currently unavailable in the United States, including considerably more intense sources of cold neutrons. This research is essential for understanding how the properties of such systems are affected by the concentration, complexing agents, and constituents of the surrounding medium.

Biology and Medicine

Studies of the structure and dynamics of biological molecules and molecular assemblies will continue to be of major interest during the next decade. The use of neutrons and photons has provided much of the major understanding that we presently have of the molecular structure of biological substances, and continued development of these uniquely useful probes is essential.

The principal growth in the use of neutrons will be in the wavelength range from 3 to 20 Angstroms. Shorter wavelengths are appropriate for the study of macromolecular crystals at the atomic level. Good facilities for such measurements presently exist at the Brookhaven National Laboratory and at the National Bureau of Standards, although additional facilities and higher intensities would be welcome.

There is a major need for further instrumentation and development in the area associated with cold neutron research. This domain will include structural studies of macromolecular assemblies at low resolution, possibly through the use of crystals but certainly with solutions. Selective deuteration methods will be extensively used. Such approaches have been used successfully in studies of the structure of lipoproteins, ribosomes, nucleosomes, and DNA-dependent RNA polymerase from *E. coli*. The analyses of many other macromolecular assemblies that may be amenable to neutron analysis now lie on the horizon, including studies of the RNA-protein complexes involved in processing messenger RNA and in controlling secretion. The higher-order structure of chromosomes is also of great interest and could be studied with neutrons of long wavelength.

Similarly, the study of biological membrane structure and the interactions of membrane components has provided a fertile area. Methodological refinements will permit a wider range of experimentation to probe both macromolecular interactions and membrane structures. Problems concerning the solvation of macromolecules, the formation of complexes between enzymes and substrates, and the interaction of ions with macromolecular surfaces are being pursued using scattering from solutions. Finally, recent applications of inelastic neutron scattering to macromolecules in solution suggest the possibility of obtaining fundamental thermodynamic parameters associated with macromolecular properties, and observing alterations in dynamic states that are correlated with functional changes in biological molecules. While this is a new area, success could lead to a greatly expanded use for inelastic scattering spectrometers that measure energy changes in the range from 0.01 to 100 meV. Thus, the needs for the coming decade in the neutron area are principally focused on the development and exploitation of instruments for cold sources.

Earth Sciences

Greatly improved energy-dispersive diffraction capability is required in the field of earth sciences. Here high-resolution diffraction of minerals at very high pressures, simulating geological stress conditions, is extremely important. Higher intensity pulsed sources will prove useful by permitting smaller samples and higher pressures to be employed. As in chemical crystallography, an order of magnitude increase in the flux from a steady state source would make it possible to greatly reduce required crystal sample volumes and open up a much larger number of mineral samples to investigation.

RESEARCH WITH MAGNET FACILITIES: PAST AND FUTURE

High magnetic field research is important for a fundamental understanding of a broad spectrum of material types and properties. Scientific advances in such diverse areas as superconductivity, permanent magnet research, and semiconductor science have all benefited from research based on the availability of intense magnetic fields. The attainment of such fields has, in general, been preceded by, and intimately connected with, applications developments and industrial commercialization. Each time a higher plateau of magnetic field strength is achieved, it is exploited quickly by the scientific community and is accompanied by the requirement for yet higher field strengths. The combination of high fields and low temperatures is particularly important, along with ancillary measuring equipment such as that associated with precision optical measurements.

The Francis Bitter National Magnet Laboratory is the primary high magnetic field research facility in the United States. Direct current (dc) fields in the 20 tesla (T) range are available using Bitter magnets. To reach higher fields, hybrid magnets utilizing both superconducting and resistive coils are required. Using such procedures, the National Magnet Laboratory has achieved a steady state field of 30.4T. The ultimate limit for dc hybrid magnets appears to be 35 to 45T, beyond which pulsed magnetic field systems are needed. The National Magnet Laboratory currently offers nondestructive pulse systems to 45T. Higher pulse fields, perhaps up to 100T, appear to be achievable using advanced technology. In addition, the National Magnet Laboratory provides limited high-field, low-temperature facilities as well as high field facilities coupled with a variety of ancillary measurement equipment.

A great deal of progress in a number of areas has been made using relatively low fields, of the order of 1 to 2T, but the number and types of useful experiments that can be performed increase dramatically with higher field strengths. For example, the Zeeman splitting of a single electron in a field of 1T is the energy equivalent of only 1.4K. Increasing the field to 100T raises the splitting to 140K, which is comparable to typical exchange and crystal field energies in many magnetic systems. This raises the possibility of inducing large changes in the electronic structures and behavior of both magnetic and nonmagnetic systems simply by applying of such large fields. Some recent examples of exciting high magnetic field experiments are studies of the fractional quantized Hall effect at semiconductor interfaces, measurements of important superconductivity parameters such as H_c in materials that have significant technological applications, and the newly observed magnetic field induced charge-density-wave transition in graphite.

Clearly, the ready availability of higher magnetic fields could enhance measurements currently being made and create new research opportunities. A study by the NRC Solid State Sciences Committee conducted in 1979 but still valid today concluded (reference 3) that the availability of higher magnetic fields would open up many new, exciting, and profitable areas of research. The study found that one of the areas profoundly affected is that of semiconductor research. As a recent example, clear data elucidating the quantized sub-integer Hall effect have been obtained in experiments up to 28T and at ultra-low temperatures (50-100 milli K). Although not totally understood, these results are thought to arise from collective effects which suggest the possibility of additional phenomena to be investigated at even higher magnetic fields and with improved ancillary conditions. Among such physical phenomena might be unusual effects associated with charge density waves and, in the low density limit, Wigner crystallization. The latter possibility is particularly interesting for a high mobility two-dimensional electron gas that can be achieved in a selectively doped semiconductor heterostructure. Such an experiment would require the 2d electron gas to be in the high field limit in order to reduce kinetic energy effects. Generally, such studies could have a major impact on improving our understanding of electron-electron correlation in an electron gas. Further, many of the techniques used to explore the electronic structure of semiconductors require that the cyclotron resonance frequency be high in comparison to the inverse scattering time of the electrons. For many materials, the scattering times are so short that this condition cannot be fulfilled with currently available magnetic fields. The only alternative in such cases is to go to higher magnetic fields. Other interesting phenomena in semiconductors that could be examined if sufficiently high magnetic fields were available include the breakdown in the effective mass approximation, electron-phonon "enhancement effects," and Zeeman splitting of deep impurity states.

Similarly, new scientific opportunities in metals and alloys emerge if intense magnetic fields are available. Many important metals and alloys have Fermi surfaces or parts of Fermi surfaces that cannot be measured at present, because either the effective mass or the electron scattering is too large. Both limitations could be surmounted in strong magnetic fields. Not only would it be possible to study the Fermi surfaces of exotic materials, but also of alloys well beyond the dilute limit. One might also envision measuring the Fermi surface of an alloy as it changed from the ordered into the disordered state. The age old problem of driving an exchange-enhanced paramagnetic system into the ferromagnetic state by applying a sufficiently large magnetic field might now be possible. Ferromagnetic Pd has not been found to date with the fields presently available. Increasing the upper limit for available magnetic fields might result in the induction of ferromagnetism in Pd.

The past several years have seen very exciting developments in the field of high-performance permanent magnet materials, especially new alloys based on the rare earth/iron/boron ternary compound, $Fe_{14}Re_2B$. The characteristics of these new materials for permanent magnets are based on large magnetization, very high magnetic anisotropy, and favorable microstructure. In a number of cases, such materials require magnetic fields in excess of 10T to achieve states near saturation. As improved materials become available, the field-intensity requirements may be even greater. The achievement of saturation fields is necessary not only in the production of permanent magnets, but in determining their fundamental properties from single crystal and oriented powder measurements. This provides a clear example of a field of research in which the availability of high magnetic fields could have a significant impact on major technological developments.

As discussed in the overview of this chapter, the study of superconductivity is the area of research that is most strongly linked to the production of high magnetic fields. Among materials currently being studied because of their interesting potential for use in high magnetic fields are the Chevrel phases, the B1 and A15 structures, as well as various types of thin film and inhomogeneous superconductors. High magnetic fields are also essential for probing those fundamental properties of superconductors that can be used to test microscopic theories, such as those associated with certain types of electron pairing--singlet, triplet, etc.--as well as other basic features of high field superconductivity.

In addition to research areas involving high magnetic fields in a very fundamental way, there is a vast array of fields involving spectroscopic and other techniques that use high magnetic fields as a probe for extracting important information about the properties of physical, chemical, and biological systems. For many of these, such as nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR), and the de Haas-van Alphen effect, the increased energy splitting available with higher magnetic fields provides tremendously enhanced ability to obtain information. At fields approaching 100T, energy splittings can also be great enough to have a direct effect on such phenomena as metallurgical phase transitions and chemical reaction rates. The ready availability of magnetic fields in these higher ranges would undoubtedly lead to a wide variety of applications and processes which utilize them in new and novel ways.

ADVANCED TECHNOLOGY NEEDS: APPLICATIONS OF NEW FACILITIES

The technological breadth of materials research can be sampled by looking at both the list of available applications in Table II.2 and the list of materials of economic importance in Table II.1. Technologically important examples have been described earlier in this chapter and are also given in numerous reports (references 1, 2, 3, 5, 6, 7, 8) dealing with synchrotron radiation, neutron scattering, and magnetic fields. Given below are examples of the connections between subareas of materials research and other fields which use major facilities and are linked to technological applications of national interest.

Semiconductors underlie all components involved in information systems--communication, computers, electronics. Techniques available at synchrotron radiation and neutron facilities are used to study structural and dynamic properties of semiconductors, including their interfaces, surfaces, and defects. X-ray scattering studies probe the atomic structure of semiconductors, while photoelectron spectroscopy techniques probe their electronic structure. Impurities of electrical importance in the range down to about 0.1 ppm or less, could be studied nondestructively using an x-ray microprobe on a new 6 GeV storage ring. High sensitivity, three-dimensional depth profiling of impurities and dopants in semiconductors and insulating films, can be studied with neutrons at concentrations down to 1 ppb if high-intensity cold neutron beams become available. X-ray lithography offers significant promise for fabricating precise submicron semiconductor structures for future VLSI applications. Doping by neutron transmutation is an essential tool for the production of semiconductor elements.

Essentially all other electronic materials, including metals, insulators, polymers, ceramics, and magnetic materials, can be characterized in unique ways using synchrotron radiation and neutrons. New structural and electronic properties of bulk and thin film materials, as well as interfaces, defects, and surfaces can be studied in novel ways.

The use of special techniques is crucial if we are to obtain an understanding of the interfaces which lie at the heart of the devices used in modern electronics. In addition to providing knowledge concerning semiconductor interfaces, synchrotron-radiation-based surface science and neutron depth profiling are also useful in exploring interfaces at junctions of metals and insulators with semiconductors, both of which represent important physical features of modern electronic devices. In the future, more intense sources offer the ability to study the time dependence of surface and interface reactions, as well as opening up the possibility of developing microfocused beam techniques.

Extended x-ray absorption fine structure (EXAFS) has been widely used by industrial researchers to study materials. Examples involve the local atomic arrangements in alloys, specific impurity sites in coal, and active sites of catalysts. EXAFS spectra have been taken of a catalyst operating in a fuel cell. Future examples include the study of new materials produced by ion implantation, studies of the role of minority elements in alloys, and studies of composites.

Increased brightness from new sources will make it possible to use smaller concentrations and to follow changes on a more rapid time scale. Parallel studies with an x-ray microprobe will offer spatial resolution as well, so that grain boundaries can be studied. Scattering studies of complex materials like oil and structural materials are providing a microscopic understanding of such materials for the first time. As was the case in the electronics industry, such understanding will contribute significantly to future innovations in the energy industries.

The availability of facilities for SANS and high-resolution neutron spectroscopy has led to revolutionary advances in the understanding of polymers and many other materials in the past decade. The availability of more intense neutron sources will greatly expand the technological uses of SANS. For example, capabilities for high-sensitivity SANS will be needed to study in-situ microstructures that determine the strength and performance of lightweight, high-strength alloys and superalloys for airframe members and engine components in military aircraft.

SANS studies of voids and very small precipitates produced in pressure vessel steels under irradiation in power reactors will provide valuable information. High-intensity, long-wavelength SANS and large-angle diffraction studies of bulk ceramics during various stages of densification as well as in-situ characterization of microcracks, pores, etc., which affect their durability, will be possible. Such knowledge may, for example, be of potential use when ceramics are employed in automobile engines. Cold neutron SANS and high-intensity neutron spectroscopy techniques will be needed for in-situ studies of the porosity, molecular behavior and interactions in new catalysts and feedstocks that are employed in the production of chemicals and fuels. SANS instruments using cold neutrons will allow the probing of biological assemblies consisting of enzymes, nucleic acids, and lipids, which control a large number of biochemical processes. These processes will often be relevant to biotechnological applications.

The unique characterization of materials with the use of high-intensity SANS will be available to study the polymeric constituents of new high-strength polymer blends and composites. This will include real time studies of phase separations related to processing. Such materials will provide increasingly important substitutes for heavier materials in autos, aircraft, and spacecraft.

Medical technologies are being advanced directly through the development of new diagnostic techniques. Moreover, the new light sources provide understanding at the microscopic level of many complex biological materials. A diagnostic example mentioned earlier is synchrotron radiation-based angiography. The study of platinum-based anti-cancer drugs by the EXAFS technique has provided clues to differences between effective and noneffective versions of these drugs. The production of medical isotopes using neutron sources will continue to be important in medical research, diagnoses, and therapy.

Synchrotron radiation and neutron facilities are important for the research programs of the defense agencies, both the Department of Energy and the Department of Defense. Advanced materials are of central importance to the defense agencies, which have needs ranging from information systems to structural materials involved in innumerable applications.

In a different class of application, remote sensors are employed in weapons tests, with particular emphasis on the hard and soft x-ray regions for diagnosis. Absolute absorption cross section spectra must be known, and detectors must be calibrated for such work. Both types of information can be obtained with the use of synchrotron radiation. While the temporal response of most detectors used in such work is faster than that of most synchrotron radiation sources, a next-generation storage ring will offer an improvement of about a factor of five.

There are several examples which illustrate the diverse applications of neutrons in research programs for national defense. High-intensity, energy-dispersive neutron diffraction is needed to measure local interaction stresses and textural characteristics which affect the performance of heavy metal shell components. Neutron depth profiling is needed to determine the tritium decay product (He^3) near the surface of refractory metals. High-intensity irradiation studies of metals and electronic components with fast neutrons are also essential.

In summary, the existing and proposed national facilities for materials research offer unique types of opportunities for both science and technology. It is difficult to think of significant issues affecting economic, defense, or health matters that cannot benefit in some essential way from the new opportunities presented by such facilities. This is, of course, the reason why they have already attracted the unparalleled participatory involvement of governmental and industrial research organizations. The new facilities considered in this report provide major opportunities for the next decade and beyond.

III. CONCLUSIONS AND RECOMMENDATIONS

The major facilities for producing synchrotron radiation, neutrons, and magnetic fields that are the focus of this report offer new opportunities essential for maintaining the progress and competitiveness of U.S. science and technology. These facilities will serve a broad spectrum of scientific fields, including materials research, biology, chemistry, atomic and molecular physics, plasma physics, the earth sciences, and medical science. As unique facilities offering incomparable scientific and technical opportunities, they will enable scientists and engineers to pursue otherwise inaccessible areas of science and technology. They will affect the technologies of information and defense, as well as those of energy, transportation, and health.

Materials research is the principal field served by these facilities. However, within this multidisciplinary field, there are also important research areas that are best served by specialized instruments of moderate cost that can be placed under the control of a single investigator or small group of investigators. Such research will often continue to be addressed most effectively by the Materials Research Laboratories and other relatively small and specialized research teams sharing comparatively small facilities, of the type described in Chapter I. Indeed, most of the research goals that the major facilities are expected to address originated through the insights of "small science" and will often be pursued jointly with groups also involved in small science.

The major materials facilities now operating--including those for neutron scattering, those for the production of synchrotron radiation, and the National Magnet Laboratory—are essential parts of the research effort of the United States. In some cases, these existing facilities will be superseded by new ones with additional capabilities. It will, however, be several years, and in some cases more than a decade, before the major new facilities recommended in this report can contribute directly to the national research effort.

The Committee emphasizes that its recommendations for major facilities--both new facilities and new capabilities at existing ones--embody two important prerequisites:

- That they are accompanied by expanded support of smaller materials research programs, including related instrumentation. Research on this scale continues to provide much of the fundamental new science in the field and to train a large fraction of our scientific and technical manpower.

- That resources must be provided to operate existing user facilities productively. In addition, the approved enhancements of major synchrotron radiation facilities at the Brookhaven National Laboratory, Stanford University, and the University of Wisconsin should be completed expeditiously, since it will require from several years to more than over a decade before the new facilities recommended in this report can contribute to the research effort of the United States.

RECOMMENDED PRIORITIES

The Committee's recommended priorities for the development and construction of facilities during the next decade include two categories:

- Major new facilities, and

- New capabilities at existing facilities.

These two categories complement one another in function, time and required resources. New capabilities at existing facilities are essential for scientific and technological needs during the next decade. The period from five years to more than a decade needed to construct major new synchrotron radiation and neutron facilities require that we start now in planning and designing these facilities. As discussed in Chapter II, failure to proceed with such new facilities will have an adverse and enduring impact on many fields of science and technology, diminishing the nation's competitive standing in such fields. The Committee concludes that both new facilities and new capabilities at existing facilities are essential for the effective evolution of science and advanced technology in the United States in the next decade and beyond.

The Committee also recommends the convening of additional panels to address other important aspects of materials research.

Major New Facilities

The Committee's recommendations for the construction of major new facilities are listed below in order of priority. A brief description and rationale is given for each recommended facility.

1. A 6 GeV Synchrotron Radiation Facility. This facility would effectively exploit the new scientific and technological opportunities made possible by insertion devices. These devices, by producing synchrotron radiation having orders of magnitude greater brightness than is currently available, would make it possible to expand on the seminal research using synchrotron radiation of the past decade. The first generation of storage rings designed as synchrotron radiation sources is now becoming operational, i.e., the National Synchrotron Light Source, at Brookhaven, and the Synchrotron Radiation Center, at the University of Wisconsin. While they will provide important capabilities, concurrent advances in design make it possible to construct storage rings and insertion devices with orders of magnitude improvement in brightness. A 6 GeV synchrotron radiation facility exploiting such advances offers both identifiable and as yet unforeseen opportunities for research not possible at present facilities.

This 6 GeV ring would have many long, straight sections containing insertion devices--undulators and wigglers. The storage ring would be designed to provide an electron beam that optimizes the emittance or intensity, or both, of synchrotron radiation from the insertion devices. A storage ring of about 6 GeV is optimal for producing undulator radiation in the 10 keV region where most x-ray research is done. The radiation from such a source would be orders of magnitude brighter than from any existing dedicated source. Wigglers on such a ring can provide unmatched intensity over a wide spectral region. The time-dependent characteristics of the radiation--short pulse length and long inter-pulse times--would make it at least as useful as that from existing sources. Moreover, insertion devices for the production of soft x-ray and vacuum ultraviolet radiation in the range from 100 eV to 1 keV would yield a thousand-fold brighter radiation than any source now operating, although not as bright as those possible on a new 1 to 2 GeV ring (Priority 3).

Timely construction of a 6 GeV synchrotron radiation facility would give the United States continued leadership in this important and dynamic field. Site-independent design should begin immediately, and the choice of site and construction should commence as soon as possible. If construction begins, for example, in FY 87, operation is possible by FY 92.

2. An Advanced Steady State Neutron Source Facility. The goal is to achieve about ten times the flux of existing machines with a minimum requirement of five times the flux. There are two principal reasons for the priority.

First, and most important, a new high-flux source can be designed to optimize beam geometry and flux distribution, so as to yield increased intensities for all experiments. An increase of about ten times the flux of existing machines is an aggressive but technologically feasible goal. Neutron scattering is inherently a signal-limited technique. The new facility would greatly increase the range of neutron experiments in materials research and other fields, as well as the precision with which relevant energies and momenta could be measured.

Such a neutron source would ensure the United States a leading position in this field, especially in the cold neutron range, where flux increases of an order of magnitude can be achieved. Such increases offer new capabilities, for example, in high resolution spectroscopy and studies of small angle scattering.

Second, the current high-flux reactors in the United States were all commissioned in the 1960's, so that there are significant concerns about their long-term viability. Given that design and construction of a new facility will require about a decade, planning must begin now to furnish needed capability for the late 1990's and beyond.

The Committee suggests that the design and construction of a new facility include the following: (a) at least one large guide hall containing many large-area guide tubes for cold and thermal neutrons; (b) a reactor hall containing many thermal beams, along with several "hot source" beams for high-energy neutron research; (c) a variety of spectrometers, including many with new capabilities beyond present designs; and (d) improved national facilities for isotope production, irradiation of materials, neutron activation analysis, and research in nuclear physics.

Instead of upgrading an existing reactor, a new facility should be built, and site-independent design should begin immediately. Because of the complexity of safety requirements, the Committee does not expect construction to begin until about FY 89, with completion possibly by FY 96.

3. A 1 to 2 GeV Synchrotron Radiation Facility. The Committee has concluded that, while the 6 GeV storage ring can furnish important new capabilities for the lower-energy region, a single such facility may not provide adequately for the national opportunities of the next decade. Among the reasons for this are: (a) the optimum storage ring energy for producing fundamental undulator radiation with wavelengths in the range of 10 Angstroms and greater is about 1.5 GeV, a region offering special opportunities for research in chemical physics and electron spectroscopy; (b) in addition to an increase in brightness, the unwanted total power density associated with a 1 to 2 GeV ring is significantly lower at wavelengths longer than 20 Angstroms; and (c) the undulator radiation from a 1 to 2 GeV source will have a higher degree of coherence than that from undulators elsewhere, thereby opening opportunities to apply various imaging techniques, such as microscopy and holography. A 1 to 2 GeV facility would provide optimal flexibility for both VUV and soft x-ray users.

This facility, then, would be centered around insertion devices but optimized for high brightness in the soft x-ray and VUV synchrotron radiation regions. The growth of research using these spectral regions has paralleled that in the x-ray region. Moreover, major advancements in design have occurred, permitting large increases in brightness for such a source.

4. A High-Intensity Pulsed Neutron Source Facility. Pulsed neutron facilities offer the best capability for sources of high-energy neutrons and the most promising approach to future advances beyond those that appear possible with steady state sources. In the few years that pulsed sources have been available, they have led to innovative research using new time-of-flight techniques and have served a broad user community, even though limited to modest peak fluxes.

The new capabilities recommended at existing facilities, for example, the attainment of a 10^{16} neutrons/cm^2-sec peak flux at the Los Alamos National Laboratory facility—Priority 3 in new capabilities given below—are expected to advance research using pulsed neutrons even further. Action on the design and construction of a pulsed source with a peak flux in the range of 10^{17} neutrons/cm^2-sec should be based upon the results obtained from such new capabilities.

New Capabilities at Existing Facilities

The Committee's recommendations for adding new capabilities at existing facilities are listed below in priority order. Brief rationales and descriptions are given for each recommendation.

1. Centers For Cold Neutron Research. Guide halls and instrumentation for exploiting the only cold neutron sources in the U.S., located at the Brookhaven National Laboratory and the National Bureau of Standards facilities, should be developed in an orderly fashion.

These facilities are urgently needed to address the rapid expansion of neutron applications in materials science, chemistry, and biology; many central problems in those fields can only be solved using new instruments with cold neutron beams. These centers will provide a diverse, flexible array of cold neutron instruments, matching current capabilities in other industrialized nations. Further, by using advanced techniques for beam focusing and polarization, such facilities would exceed existing worldwide capabilities, in areas such as high resolution spectroscopy of catalysts and polymer systems and in studies of impurities and inhomogeneities in bulk materials.

Research using cold neutron facilities has received inadequate support in U.S. during the last decade, a period of major investments in cold neutron research in other countries. The Western European investment alone is at least ten times that of the United States. There are only two cold neutron reactor sources in the United States one at Brookhaven and one being developed at the National Bureau of Standards. Guide halls, which improve the versatility and flexibility of cold or thermal neutron instruments, do not exist in the United States while there are six fully instrumented cold neutron guide halls either completed or under development in Western Europe. Implementing this priority will enable U.S. scientists to be competitive in cold neutron research during the next decade and will provide new instrumentation concepts for developing future neutron scattering facilities.

2. Insertion Devices on Existing Facilities for Synchrotron Radiation. Insertion devices and instruments should be developed in an orderly fashion to exploit about six of the remaining straight sections

of existing storage rings. The special characteristics of undulators as radiation sources should be emphasized, since they enable new capabilities not available presently at existing facilities.

Existing storage rings fitted with insertion devices will be our premier sources of synchrotron radiation for the next 5 years or more, or until new facilities described in this report are completed. Further, they will provide valuable experience for designing and implementing our next generation of synchrotron radiation facilities.

There are, currently, only four operational insertion devices, all wigglers. Nine new insertion devices have been proposed and approved for funding, of which only three are undulators. This number of insertion devices is clearly inadequate to meet future national needs and requires the development and implementation of additional devices.

Thus, the construction of additional insertion devices, when it is approved, should follow the construction of new capabilities at synchrotron radiation facilities already included in the budgets for FY 85 and FY 86.

3. Experimental Hall and Instrumentation at the Los Alamos National Laboratory. An experimental hall and new instruments at the Weapons Neutron Research/Proton Storage Ring (WNR/PSR) pulsed neutron source at the Los Alamos National Laboratory (LANL) would make the United States competitive in pulsed neutron research and would help guide the development of future pulsed sources. The expected flux increase at this facility provides an important opportunity to explore, at modest cost, the great promise of pulsed neutron science in relation to spectroscopic and structural problems. Although this technology is young, the instruments developed at the Argonne and Los Alamos national laboratories demonstrate that innovative approaches can produce enhanced capabilities.

Pulsed sources are superior to steady state sources in generating neutrons of short wavelength. It also appears that instruments for pulsed sources can be developed that will be advantageous at long wavelengths in certain cases. Developing the new source at the WNR/PSR at Los Alamos should, for a relatively modest investment, provide an important new tool for research and also permit a detailed assessment of the best course for developing future pulsed sources. Overall, the Committee feels that the WNR/PSR facility should be exploited fully. In considering the specific opportunity at Los Alamos, important factors taken into account were the peak intensity that could be attained (greater than 10^{16} neutrons/cm^2-sec), the relative economy of the investment, and the speed with which the facility could become operational.

4. Upgrade of the National Magnet Laboratory. The National Magnet Laboratory (NML) is the only high magnetic field user facility in the United States. Many areas of materials research require combinations of high fields and/or low temperatures. Both the 45T pulsed field system and the 19T/50 mK system at the NML require enhanced instrumentation to permit full exploitation. The position of NML as the leader in magnetic field research depends on the timely development of a new hybrid system that will provide higher fields at lower cost for a rapidly growing community of users. Additional funds are needed to

complete the project. A pulsed magnetic field system capable of 75T could also be placed on line more quickly with adequate funding. Recent experience shows that even modest increases in magnetic field capability can open new approaches for addressing important problems in condensed-matter science and increase the demand for NML facilities significantly.

5. Enriched Pulsed Neutron Source Target. Enriched targets exploit higher levels of fission to amplify the production of neutrons and can more than double the available flux. Such increases in flux are important because neutron scattering is inherently a signal-limited technique. The development and installation of enriched targets for use at pulsed neutron facilities would be cost effective.

Priorities 1 and 2 for major new facilities, when they are implemented, would serve as a centerpiece of this nation's future capability for synchrotron radiation and neutron based research. Thus, design and siting studies for a 6 GeV synchrotron radiation facility and for an advanced steady state neutron facility should begin immediately.

Because of the long lead time associated with an advanced steady state neutron facility, the immediate implementation of at least one instrumented cold neutron guide hall is necessary to provide forefront capability.

ESTIMATED COSTS OF THE RECOMMENDATIONS

To summarize the overall scale of its recommendations, the Committee presents, in Table III.1, its estimates of the requirements for new funding in millions of FY 85 dollars. The estimates in Table III.1 include costs of construction and initial instrumentation for major new facilities and new capabilities at existing facilities. Estimates for major new facilities assume initial instrumentation for one-half of the available beam line capability.

There are also additional costs associated with the development, maintenance, and scientific use of these advanced facilities. The Committee estimates related personnel costs to be about $250 thousand per year for each neutron or synchrotron end station. The same is true for major new magnetic field stations. A somewhat smaller amount is required for other experimental purposes and/or instrument maintenance. More detailed information can be obtained from the presentations included in the supplemental volume to this report. In addition, there will obviously be some incremental travel, subsistence, and experimental costs for the hundreds of scientists and engineers who will use these new facilities, costs which may be covered only in part by reassignment of funds used for other scientific purposes.

Table III.1 REQUIREMENTS FOR NEW FUNDING*

MAJOR NEW FACILITIES (Millions of FY 85 Dollars)

In order of priority:

1.	6 GeV SR Facility	$ 160
2.	Steady State Neutron Source Facility	260
3.	1 to 2 GeV SR Facility	70
4.	High Intensity Pulsed Neutron Source Facility	330

NEW CAPABILITIES AT EXISTING FACILITIES (Millions of FY 85 Dollars)

In order of priority:

1.	Centers for Cold Neutron Research	$ 25-35 each
2.	Insertion Devices on Existing SR Facilities	20
3.	Experimental Hall and Instrumentation at LANL	15
4.	National Magnet Laboratory Upgrade	5
5.	Enriched Pulsed Neutron Target	2-5

---

* The Committee's estimates for construction and initial instrumentation costs are largely based on information from facility presentations, program officers, and other knowledgeable colleagues.

Major New Facilities

1. The new 6 GeV synchrotron radiation facility has an estimated cost of $160 million, including $125 million for construction and $35 million for instrumentation. The instrumentation would equip fully about 10 insertion devices, and associated beam lines, with about 20 experimental end stations. The estimated operating cost is about $20 to $25 million per year.

2. The new steady state neutron source has an estimated facility cost of $260 million, including $220 million for construction and $40 million for about 20 instruments. The estimated operating cost is $12 million per year.

3. The 1 to 2 GeV synchrotron radiation facility is estimated to cost $70 million, including $50 million for construction and $20 million for the instrumentation of 6 instrumented beam lines with about 12 end stations. The estimated operating cost is $9 million per year.

4. The high-intensity pulsed neutron source facility is estimated to cost $330 million, including $310 million for construction and $20 million for instrumentation of about 15 instruments. The estimated operating cost is $25 million per year.

New Capabilities at Existing Facilities

1. The centers for cold neutron research would cost $25 to 35 million each, about half for guide hall construction and half for instrumentation. The instrumentation funding would provide up to 20 cold neutron instruments and associated equipment. There are no incremental operating costs for the reactor associated with these new capabilities.

2. Insertion devices on existing synchrotron radiation sources would cost about $20 million for 6 fully developed lines, including about 12 x-ray and VUV instruments. There are no incremental operating costs for the associated synchrotron sources.

3. The experimental hall and instrumentation at the Los Alamos National Laboratory would cost $15 million and provide a large area for the installation of more than 10 instruments, 3 of which would be funded as part of the LANL proposal. Additional pulsed source operating costs of $2.7 million per year are required.

4. The National Magnet Laboratory upgrade requires about $5 million.

5. An enriched pulsed neutron target would cost between $2 and 5 million. Operating costs for the source would increase between $0 and 0.7 million.

Current major facilities will likely be superseded by the new facilities in certain cases, and their operating cost budgets will be transferred. An example is given by the steady state neutron source, whose construction could result in the phasing out of one of our current sources. This, in turn, would have the effect of requiring only a slight increase in net operating costs for the new facility.

The Committee considered possible funding schedules for each of the foregoing recommendations. In general, the new capabilities at existing facilities can be implemented within about 3 years from initial funding, whereas the major new facilities are estimated to require construction times from about 5 years to as long as 10 years.

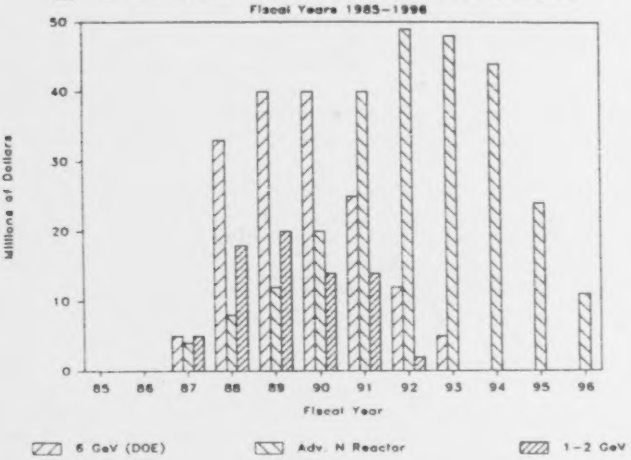
In response to its charter, the Committee has determined the order of priority of construction of new facilities that are important for the rapid and effective progress of materials research and related fields. We show in Figure III.1 an estimated funding profile for design and construction associated with an expeditious implementation of all the items in these priority lists except for the 10^{17} neutrons/cm^2-sec pulsed neutron source facility, whose starting date is uncertain. The Committee does not necessarily recommend that all priorities be funded at the respective times indicated. The diagram is intended to suggest the approximate earliest possible start dates and construction time intervals for the various priorities. We note that accurate estimates of both construction costs and time schedules can only be obtained from specific proposals from specific institutions. The funding profile for priority 2 shown in Figure III.1b extends from fiscal years 1987 to 1989. Under this schedule, priority 2 modifications would follow the completion of those new capabilities at existing synchrotron facilities that are already included in the budgets for fiscal years 1985 and 1986.

With the foregoing in mind, several important general conclusions can be deduced from Figure III.1. First, implementation of new capabilities at existing facilities is complementary in time to the implementation of major new facilities. Second, with modifications of schedule, a relatively flat funding profile of construction is possible over the next decade, with an average expenditure rate of roughly $50 million per year for about a decade if all priorities are implemented. Third, the total construction fund of $588 million appearing in Figure III.1 is roughly comparable, in FY 85 dollars, to the average total U.S. capital investment per decade over the past two decades to provide facilities for synchrotron radiation, neutron production, and high magnetic fields, namely, in the range of $300 million, $500 million, and $20 million, respectively.*

---

* The replacement costs in FY 85 dollars for existing multi-purpose neutron sources and related major instrumentation built over the past 20 years (primarily in the 1960's) is of the order of $500 million. This includes, for example, the HFIR at Oak Ridge, the HFBR at Brookhaven, the NBS reactor, the University of Missouri reactor, and the intense pulsed neutron source at Argonne. A comparable figure for synchrotron radiation sources and associated instrumentation (primarily developed over the past decade) is estimated at about $300 million including facilities at Brookhaven (NSLS), Stanford (SSRL), Wisconsin (Aladdin, Tantalus), Cornell (CHESS), and NBS (SURF II). Estimates for the synchrotron radiation facilities includes the construction cost of SPEAR at Stanford but does not include any share of other accelerator facilities used in a parasitic mode for synchrotron radiation at Cornell and Stanford.

A. ESTIMATED COSTS: NEW FACILITIES



B. ESTIMATED COSTS: NEW CAPABILITIES

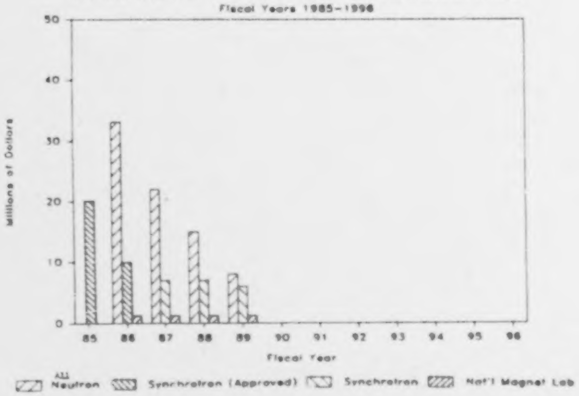


FIGURE III.1. Estimated Costs Versus Year. Estimated costs and earliest possible schedules for construction and initial instrumentation of (a) a 6 GeV synchrotron radiation facility, an advanced steady state neutron source, and a 1-2 GeV synchrotron radiation facility and (b) all recommended priorities for new capabilities at existing facilities.

The funding profile for priority 2 shown in Figure III.1b extends from fiscal years 1987 to 1989. In this schedule, modifications associated with priority 2 would follow the completion of those new capabilities at existing synchrotron facilities that are already included in the budgets for fiscal years 1985 and 1986. The Committee does not necessarily recommend that all priorities be funded at the respective times indicated.

OTHER SPECIALIZED FACILITIES CONSIDERED BY THE COMMITTEE

In addition to facilities for synchrotron radiation, neutron scattering, and high magnetic fields, the Committee surveyed other major facility needs and opportunities during the course of its study. However, none was identified that qualified for the priorities under the guidelines, namely $5 million minimum cost, established by the Committee's charter. We summarize here the specific items considered and the reasons for excluding them from detailed considerations.

Medium-Scale Specialized Facilities

The Committee briefly considered interdisciplinary materials research organizations, such as the Materials Research Laboratories (MRL) funded by the NSF and DOE, as well as special-purpose materials research laboratories or such centers for materials research as those on polymers, ceramics, and materials processing and other focused sub-areas of materials research. The Committee believes that such laboratories and centers represent a very important part of our overall national materials research program and that they fulfill national needs not otherwise satisfied by academic, governmental, or industrial laboratories.

The Committee heard excellent arguments for new facilities of this type, each of which can easily cost more than $5 to 10 million. However, the Committee excluded consideration of them without prejudice. It did so in part because of their "open-ended" nature. They require fuller definition through the formulation of specific proposals by specific institutions. The Committee did not request development of the details of such proposals when they were not already well formulated. Further considerations of important materials research laboratories and centers are deferred for future planning committees.

The Committee also discussed facilities for developing microelectronics processes. These are rapidly gaining national importance as microelectronic technology reaches submicron levels in silicon, and as materials other than silicon, such as gallium arsenide, are explored. Most large-scale facilities for microelectronics processing have, quite appropriately, been established by industry, though there is also a role for universities in this area.

Also discussed were facilities for high and ultra-low temperatures as well as those involving charged-particles such as electron microscopes and ion beam facilities, which can make major contributions to the analysis, synthesis, and modification of materials. The individual costs of these generally fall below the $5M threshold used by the Committee. As a result, and without passing any judgment on relative merits, such facilities would be better considered as part of the analysis of serious instrumentation needs mentioned earlier in this report. Such instrumentation will play important roles in conjunction with the use of synchrotron radiation sources, in which case their costs will be included along with those of beam lines.

Specialized Photon Sources

The Committee examined various other photon sources, such as high peak-power VUV excimer/dye-laser schemes, transition-radiation and bremstrahlung sources driven by intense relativistic electron beams, free-electron lasers, and soft x-ray sources derived from laser-heated plasmas. VUV laser sources based on nonlinear mixing of excimer and tuneable dye lasers were judged very promising. This technology deserves rapid development. The facility costs for such sources, although quite substantial when judged by traditional academic research standards, are expected to fall considerably below the Committee's $5 million threshold. Practical realization of the other photon sources listed above would require large capital investments.

However, only the free-electron laser appears to be of general interest at this time when employed in a user mode, because of its high brightness and broad tunability. This technology is currently under active development at many laboratories, both in the United States and abroad. The eventual utilization of free-electron lasers operating in the infrared seems a certainty. Efforts should be made to stimulate the establishment of a user community. The practical short-wavelength limit of such systems is not yet known, although operation of such lasers to 50 nm (5 nm with harmonic generation) has been projected. Considerable development effort is needed, particularly with regard to high-reflectance mirrors in this spectral region. Although it is premature to rank the value of free-electron lasers, they may eventually prove to be extremely important at photon energies in the range of 10 to 100 eV, and thus complement VUV/soft x-ray synchrotron radiation sources.

Computation Facilities

As indicated in Chapter I, the Committee also made an effort to examine the growing importance of large-scale computational support in the materials sciences. Theoretical materials science has now reached a point where, given adequate computer support, it can predict with quantitative accuracy, typically 1 to 10 percent, the physical properties of many materials systems, and thus complement experimental approaches.

The most effective kind of computer support for the national materials science community therefore is provided by a combination of a national network of Class 6 supercomputers and a number of smaller computers that are used by local or regional groups. The Committee strongly supports a major initiative in this direction now being undertaken by the National Science Foundation. It also strongly supports plans of the Department of Energy to extend the availability of networked supercomputers to scientists working in other areas. It hopes that other agencies supporting basic research will also take appropriate actions.

Muon Facilities

Pulsed muon beams, derived parasitically at high-energy particle accelerators, have received considerable attention for studies of condensed-matter physics that are based on measurements of spin-rotation. Several centers which support such research currently exist, and modest growth is anticipated. Some thought is being given to a major dedicated beam line at the Los Alamos LAMPF proton storage ring. The cost for such an addition may reach $30 million. It appears premature to judge the merit of such a facility, given the currently small size user community and the highly specialized nature of the technique.

Engineering Materials Test Facilities

Facilities in this category cover a very broad range with respect to the physical parameters studied and the associated capital costs. Major needs of this type for which federal, rather than industrial, funding is appropriate are primarily linked to mission oriented programs, such as national defense. As a result, they are not under the purview of the Committee.

Facilities Only Peripherally Related to Materials Science

Facilities whose principal purpose is not related directly to materials science were not considered by the Committee. An example is the proposal at Sandia for a Combustion Research Center (Phase II). The central thrust of this proposal is directed toward combustion science and technology. The behavior of materials at combustion temperatures is only one among a large number of other important topics projected for investigation at this laboratory as part of the new initiative.

APPENDIX A

National facilities for research in the physics of condensed matter

George H. Vineyard

Physics Department, Brookhaven National Laboratory, Upton, New York, 11973

L. M. Falicov

Department of Physics, University of California, Berkeley, California 94720

(Received 21 October 1983; accepted for publication 15 November 1983)

Brief descriptions are given of 23 national facilities in the U. S. that are of importance to research in the physics of condensed matter. These facilities range from nuclear reactors and synchrotron sources to high-voltage electron microscopes and facilities for the preparation of special materials and submicron structures. They take a variety of forms and are located in several kinds of institutions, but are alike in being available to qualified scientists from other laboratories. The primary purpose, size, major experimental equipment, and method of operation are described for each facility.

PACS numbers: 29.25.Dz, 61.90. + d, 07.80. + x, 89.20. + a

INTRODUCTION

At the American Physical Society meeting in Los Angeles in March of 1983 an invited poster session was held on National Facilities of Importance to Condensed Matter Physics. The session was arranged by the Division of Condensed Matter Physics. There were 23 facilities featured, ranging from nuclear reactors and synchrotron sources to high-voltage electron microscopes and facilities for the preparation of unique materials or submicron structures. Most of the facilities on display have come into operation within the last five years, many within the last one or two. This fact reflects the rapid increase in the importance of large research devices and combinations of large devices in condensed matter physics, together with the necessity that, because of their cost such facilities be developed on a national basis and widely shared. Thus a pattern of usage is developing in condensed matter physics which has been common in particle physics for many years, and institutional arrangements are evolving for accomplishing this objective effectively and fairly. All these central facilities are governmentally funded. Only two, however, are operated directly by the federal government; the others are operated by contractors, many in national laboratories, some in state universities.

Even though the 23 facilities included all of the very large national facilities which are of prime importance to condensed matter physics, the display was not exhaustive. Other facilities exist that were not included because of space limitations. The list, however, gives an excellent view of the present national posture. It shows that the United States is in a strong position, but also makes it clear that condensed matter physics is a dynamic area in which rapid growth and frequent change must occur. It is hoped that this review will be valuable to potential users and will assist in the wide dissemination of information on what is available and how the interested researcher goes about gaining access to these centers.

It is evident that a strong trend toward national user facilities is still in full swing, and that more centralized facilities for condensed matter research will soon become available. Decisions on what new centers are most needed should be aided by this overview of what exists now.

In the following, a short synopsis of each facility is given, including its primary purpose, major equipment, size, and method of operation. Sources from which one can obtain more information are also provided.

The facilities are grouped under the following headings: (1) neutron sources; (2) synchrotron radiation sources; (3) facilities for microanalysis, microfabrication, and surface studies; (4) electron microscopes; and (5).

The writers are indebted to the operators of the various facilities for their cooperation in supplying information.

I. NEUTRON SOURCES

Nuclear reactors have been the traditional sources of neutron beams for condensed matter physics since the 1940's. Four U. S. reactors which are national facilities are described in this section. Also included is a facility within a facility, the National Center for Small Angle Scattering Research at Oak Ridge.

More recently pulsed neutron sources driven by medium energy accelerators have come on the scene, and two of these which are now national facilities are represented.

The main focus in what follows is on neutron scattering; radiation damage in materials has not been emphasized. Most of these facilities, however, also offer capabilities for exposing specimens to various kinds of radiation.

A. High Flux Beam Reactor, Brookhaven National Laboratory, Upton, NY

The High Flux Beam Reactor (HFBR) provides the scientific community with one of the most intense thermal neutron sources in existence today. The HFBR began operating in 1965 at a power of 40 MW. It has had a cold neutron

0034-6748/84/040620-11$01.30

© 1984 American Institute of Physics

facility with liquid-hydrogen moderator operating since April 1981. The reactor was recently upgraded and has been operating at 60 MW since September 1982. Many types of experiments are possible at the HFBR, including magnetic and nonmagnetic structure studies, phonon and magnon dispersion measurements, and diffuse scattering studies. Because of the relatively high energy resolution and the sensitivity of neutrons to magnetic moments and to the nuclei of almost all elements of the periodic table, neutron scattering makes feasible many studies which would be difficult or impossible with x rays. Facilities of interest to solid-state physicists at the HFBR include several triple-axis neutron spectrometers which can be used for both elastic and inelastic scattering measurements with incident neutron energies between 2 and 200 meV. A wide variety of different sample environments is available, including temperatures from 35 mK to 1500 K, magnetic fields up to 7 T, and pressures up to 35 kbar.

For additional information contact B. H. Grier or G. Shirane, Physics Department, Brookhaven National Laboratory, Upton, NY 11973.

B. High flux isotope reactor, Oak Ridge National Laboratory, Oak Ridge, TN

The High Flux Isotope Reactor[5] serves the condensed matter physics community by providing high-intensity beams of thermal neutrons. The scattering facilities available include eight different instruments, not counting the 30-m Small-Angle Neutron Scattering (SANS) instrument described elsewhere. They are: (1) the triple-axis polarized-beam spectrometer, which permits polarization analysis experiments; (2) and (3) two general-purpose triple-axis spectrometers used for most of the phonon dispersion measurements, but which are also useful for modest resolution quasielastic studies and fairly high resolution powder diffraction studies; (4) a liquid diffractometer with a linear position-sensitive detector; (5) a double perfect-crystal, very-high-resolution SANS spectrometer which has been used primarily to study vortex lattices in superconductors; (6) a four-circle diffractometer for crystallographic studies; (7) a more limited triple-axis unit with a fixed incident energy of 14.7 meV; and (8) a time-of-flight correlation chopper spectrometer. The latter has been equipped recently with a system of ultrasonically pulsed silicon crystals to monochromatize and pulse the neutron beam incident on the sample.

A new two-dimensional detector has been developed; it utilizes a 12-in.-diam neutron-sensitive LiF–ZnS phosphor, an image intensifier, and a television camera system. This detector has been extremely useful in the observation of diffuse scattering, superlattice formation, and powder patterns, as well as crystal characterization, all in real time (less than a second). The system also has image storing capabilities.

Some of the auxiliary equipment includes furnaces, closed-cycle refrigerators, helium-four cryostats, a helium-three cryostat, a superconducting magnet, and a helium-three–helium-four dilution refrigerator with a split-coil superconducting magnet, which is capable of reaching 7 mK and a field of 5 T.

For additional information contact H. A. Mook, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

C. Research reactor facility (MURR), University of Missouri, Columbia, MO

The University of Missouri operates a 10-MW reactor as a neutron and gamma radiation source for condensed matter research. Interested parties from outside the University are encouraged to make use of the facility through cooperative experiments with members of the staff, or through the Reactor Sharing Program, supported by the Department of Energy. At MURR there are facilities to conduct experiments in at least four areas related to condensed matter physics research. (1) For neutron scattering, two triple-axis spectrometers are available to measure dispersion relations; two single-crystal diffractometers and one powder diffractometer are available to measure atomic and magnetic ordering in condensed matter systems; one small-angle neutron scattering spectrometer is available for polymer and molecular biological studies; a neutron interferometer can be used for special experiments. (2) For gamma scattering, three unique instruments are available: MUGS, which is a gamma-ray diffractometer for structure studies; QUEGS, which is a gamma diffractometer with Mossbauer energy analysis for quasielastic gamma measurements; and COGS, which is a Compton spectrometer now available for measuring momentum distribution of electrons. (3) Trace element analysis can be done by instrumental, radiochemical, and prompt neutron activation; it allows the characterization of elements in condensed matter samples. (3) Analyses of deep levels in the band gap of semiconductors can be made by using deep-level transient spectroscopy, current transient spectroscopy, and the newly developed charge transient spectroscopy, which allows 10^{10} deep levels per cubic centimeter to be detected.

For additional information contact R. M. Brugger, Director, Research Reactor Facility, Research Park, Columbia, MO 65211.

D. NBS research reactor, National Bureau of Standards, Gaithersburg, MD

The NBS research reactor is expected to double its power to 20 MW by the end of 1983. In March of 1983 it had 25 experimental facilities installed for materials reseach, activation analysis, radiation standards, and nuclear physics. Ten of the horizontal beam ports are dedicated to condensed matter science, with a wide variety of neutron scattering instruments installed. Special features include: (1) a three-axis spectrometer with two low background analyzer systems to allow measurements ranging from soft modes and spin-wave excitations in solids (as low as 1.0 meV) to the spectroscopy of low levels of hydrogen and molecular species in metals and catalysts (30–300 meV); (2) a multidetector high-resolution diffractometer used to study complex structures by powder diffraction, e.g., magnetic intermetallic compounds, catalysts, and ionic conductors; (3) a biological diffraction station used to study the structure of proteins; (4) a depth profiling facility for the nondestructive determination of density profiles of selected elements near surfaces; and (5) a small-angle neutron scattering facility with continuously variable wavelengths from 4 to 10 Å, a wave vector transfer range from 0.003 to 1.0 $Å^{-1}$, and on-line color graphics for the study of microstructure in metals, polymers, and biological materials.

For additional information contact J. J. Rush or J. M. Rowe, National Bureau of Standards, Washington, DC 20234.

E. National Center for Small-Angle Scattering Research, Oak Ridge National Laboratory, Oak Ridge, TN

The National Center for Small-Angle Scattering Research is a user-dedicated facility supported by the National Science Foundation and the Department of Energy under an interagency agreement. The two main instruments available to users are the NSF-supported 30-m small-angle neutron scattering facility (SANS) and the DOE-supported 10-m small-angle x-ray scattering camera (SAXS). These instruments are intended to provide state-of-the-art capability for investigating condensed matter structures in a range from a few tens up to several hundreds of angstroms. They are intended to serve the needs of scientists in the areas of biology, polymer science, chemistry, metallurgy and materials science, and solid-state physics.

For additional information contact W. C. Koehler, Director, or M. Gillespie, Secretary, NCSASR, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

F. Intense Pulsed Neutron Source, Argonne National Laboratory, Argonne, IL

The Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory (ANL) is the most intense neutron spallation source now operating in the world. Protons from a 50-MeV linear accelerator and a 500-MeV rapid cycling synchrotron are delivered to a uranium target at a frequency of 30 Hz to produce neutrons. In the first year of operation 3370 h of research time were available. The peak thermal flux of IPNS is 3×10^{14} n/s cm^{2}.

The instrument package at IPNS has been designed with particular attention to the rich epithermal spectrum of neutrons present in such a spallation source. For example at 500-MeV IPNS has an effective flux approximately 10 times greater than the hot source at the Institute Laue Langevin (Grenoble, France).

The instruments for elastic or total scattering consist of two powder diffractometers (one a general purpose diffractometer and one a special environment diffractometer) which have excelled at high-resolution work and have also proven useful for studying amorphous systems. A single-crystal diffractometer is based on the Laue technique with a position-sensitive two-dimensional (30 × 30 cm) detector. A small-angle diffractometer also includes a position-sensitive detector, and is used for both metallurgical and biological problems. Of particular interest is the possibility of using epithermal neutrons in resonance small-angle scattering on biological molecules.

For inelastic scattering the crystal-analyzer spectrometer is particularly well suited to examine dispersionless high-energy vibrational modes. Two chopper spectrometers have proved exceptionally versatile in a variety of problems involving measurements of inelastic cross sections.

A new instrument, an electron-volt spectrometer, is under construction.

In the first year of operation approximately 120 experiments were performed at IPNS in the 3370 h of research time that was available. People from 23 universities, 5 industrial laboratories, 5 U. S. National Laboratories, and 8 foreign institutions were involved.

For additional information contact T. G. Worlton, Scientific Secretary, IPNS, Argonne National Laboratory, Argonne, IL 60349.

G. Weapons Neutron Research/Proton Storage Rings (WNR/PSR) Facility, Los Alamos, NM

The WNR is already operational as a high-intensity spallation neutron source. The user program was scheduled to begin in September 1983. Two-thirds of the neutron scattering beam time will be allocated for outside use and one-third reserved for in-house use. The first two user instruments will be the Be–BeO filter difference spectrometer (especially suited for chemical spectroscopy, and for studies of density of vibrational states and of optical modes of solids), and the single-crystal diffractometer (wavelength-resolved Laue camera). New instruments will be added to the user program as they become available and reach maturity. The tentative list of WNR instruments with their year of first operation and projected year for entry into the user program is: (1) filter-difference spectrometer (1980, 1983); (2) single-crystal diffractometer (1980, 1983); (3) liquids, amorphous, and special environment diffractometer (1980, 1984); (4) powder diffractometer (1980, 1984); (5) constant wave-vector-change spectrometer (1983,1985); (6) electron-volt spectrometer (1980,1985); (7) chopper spectrometer (1984,1986); and (8) small-angle diffractometer (1986,1987).

Some highlights of the research program to date include: (1) model-independent determination of the hydrogen–hydrogen pair correlation function in liquid water; (2) determination of the structure of the first molecular hydrogen complex; (3) observation of a new correlation of hydrogen bond vibrational frequencies with bond length for very short hydrogen bond; (4) development of the nuclear-resonance filter-difference method for electron-volt spectroscopy; and (5) observation of hydrogen momentum distributions in hydrides and water by scattering in the impulse approximation.

For additional information contact R. N. Silver, Group P-S, MS-H805, Los Alamos National Laboratory, P. O. Box 1663, Los Alamos, NM 87545.

II. SYNCHROTRON RADIATION SOURCES

The five synchrotron radiation sources in the United States are described here. The newest entrant in the field, the NSLS, is still in the process of coming into full-scale operation, and the others are still undergoing enlargement and improvement. This is a rapidly growing area of research throughout the industrialized world.

Figure 1 is an aerial view of the Stanford Synchrotron Radiation Laboratory.

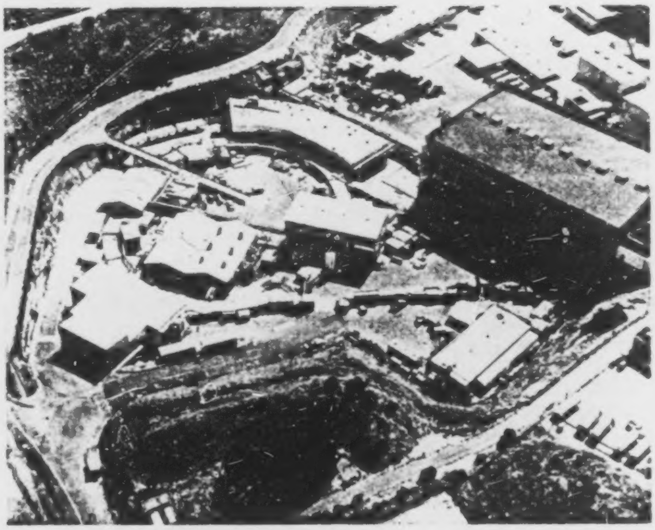


FIG. 1. An aerial view of the Stanford Synchrotron Radiation Laboratory.

A. Standford Synchrotron Research Laboratory (SSRL), Palo Alto, CA

SSRL is a national facility for the utilization of synchrotron radiation in biology, physics, materials science, medical science, and other disciplines. It is funded by the Department of Energy. The radiation comes from the storage ring, SPEAR, a facility within the Stanford Linear Accelerator (SLAC) built originally for high-energy physics research.

SPEAR is dedicated to the production of synchrotron radiation half of its operating time. During this time high currents of electrons, up to 100 mA are stored at high energies (3–3.5 GeV). The other half of the time the ring operates for high-energy physics research purposes to produce colliding beams of electrons and positrons. The ring is in operation between 8 and 9 months out of each year.

In addition to scientific research the Laboratory had a commitment to the development of advanced insertion devices for the enhancement of synchrotron radiation and the development of state-of-the-art instrumentation for the utilization of synchrotron radiation.

At present SSRL has 16 experimental stations on five beam lines covering the spectrum from 6 to 40 000 eV. A wide variety of experimental equipment is available for the user, and there are no charges either for the use of the beam or of the facility-owned support equipment. Both a 54-pole wiggler line and an undulator beam line serving three experimental stations are being developed; they will cover a range from 10 to 1000 eV.

SSRL is currently used by approximately 550 scientists from 124 different institutions, including universities, private corporations, and government laboratories.

As of March 1983 a total of 797 proposals had been received since March 1974, out of which 190 were active. A typical project involves four to eight scientists, including graduate students and post doctorals. Approximately 100 graduate students from 15 different universities work at SSRL each year. Over 200 publications based on research conducted at SSRL appear in journals each year.

For additional information contact A. Bienenstock, Director, Stanford Synchrotron Radiation Laboratory, P. O. Box 4349, Bin 69, Standford, CA 94305.

B. Cornell High Energy Synchrotron Source (CHESS), Cornell University, Ithaca, NY

CHESS, the Cornell High Energy Synchrotron Source, is a national laboratory which provides six x-ray experimental stations. X rays come from an 8-GeV electron storage ring (CESR). Monochromatic tunable photon beams from 4 to 100 keV are available. A six-pole 1.8-T wiggler provides a particularly intense spectrum with a critical energy in excess of 30 keV. The CHESS x-ray spectrum has a unique time structure—pulses come at 2.56 μs intervals with a pulse width of 0.13 ns.

Two stations provide white-beam capabilities, particularly useful for topography, high-pressure studies, and experiments that contain their own unique monochromators. A four-axis Huber diffractometer and two Picker diffractometers are available for diffraction physics experiments. Two complete EXAFS stations with data-acquisition software and off-line analysis packages are provided.

CHESS is supported by the National Science Foundation and currently provides experimental capabilities for approximately 100 active research proposals from all over the U. S. A.

For additional information contact Nancy Miller, Proposal Administrator at CHESS, Wilson Laboratory, Cornell University, Ithaca, NY 14853.

C. National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY

The National Synchrotron Light Source (NSLS) is designed to provide the world's brightest continuous source of x rays and UV radiation. It is also the first x-ray facility in the United States dedicated for use as a synchrotron light source. It consists of two electron storage rings, one at 750 MeV for the production of vacuum ultraviolet (VUV) radiation, and one at 2.5 GeV for the production of x rays. In mid-1983 the VUV storage ring was in reliable operation with currents up to 300 mA and a lifetime of 2 h at 100 mA. The x-ray ring had stored beam, and initial operation for experimenters was expected during the latter part of 1983.

The VUV ring has 16 ports for VUV and IR research. It incorporates a unique free-electron laser designed to be a narrowband (relative bandwidth of 10^{-4}), continuously tunable (2000–4000 Å) UV source with average power in the range from one to several watts. The free-electron laser undulator can be used during routine storage ring operations to produce intense radiation between 100 and 2000 Å. The x-ray storage ring has 28 ports. Each of the 16 VUV and 28 x-ray ports is divided into two or three individual beam lines.

Under construction are several wiggler and undulator magnets which will significantly increase the photon energy and brightness.

The facility has a wide range of research equipment for basic and applied studies in condensed matter, surface science, photochemistry and photophysics, lithography, crystallography, small-angle scattering, metallurgy, x-ray microscopy, etc.

The NSLS is a national user facility, available without charge to university, industrial, national laboratory, and government users. There are several modes of use of the experimental facilities. A large number of beam lines have been designed and constructed by 27 participating research teams (PRTs). The PRTs are, for most part, user groups from outside Brookhaven National Laboratory with large, long-range programs which have been approved by the NSLS Program Advisory Committee. The PRTs are given priority for up to 75% of the operational time of their beam lines. General users will be scheduled for both PRT beam lines and for lines built by NSLS for the community in general.

For additional information contact M. Blume, Chairman, National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973.

D. Synchrotron Radiation Center, University of Wisconsin, Stoughton, WI

The Synchrotron Radiation Center (SRC) of the University of Wisconsin operates the Tantalus 240-MeV electron storage ring and is bringing on line the Aladdin 1-GeV ring. When Aladdin is in operation, it will have 35 equivalent bending magnet source points and one inverse Compton scattering source point. Ten beam lines will be fully implemented and maintained by the SRC. Monochromators will span the spectral range from about 4 to 1200 eV; there are plans to develop a soft x-ray crystal monochromator to extend the range to 4000 eV. Beam lines and monochromators will be available to users on a request-for-time basis. Since no single monochromator is able to span the entire range made available by Aladdin, requests for beam time should be specific on the choice of monochromator or the spectral range needed.

In addition to the ten facility beam lines, thirteen beam lines are being implemented by groups of users, called participating research teams (PRTs), each with its own specific purpose. Access to these instruments will be possible through negotiations involving the SRC director and the PRT involved.

When completed, Aladdin will have 23 monochromators operating on 21 beam lines, including five high-flux Seya-Namioka's (5–50 eV), three normal-incidence monochromators (including a 4-m ultrahigh resolution instrument), five toroidal grating monochromators (6–180, 225, and 700 eV), three high-resolution grasshoppers (20–1,000 eV), five high-resolution extended range grasshoppers (5–1500 eV), and a soft x-ray emission spectrograph. In addition, one x-ray crystal/grating (800–4000 eV) instrument has been authorized and a second is proposed.

Special facilities planned include an inverse Compton scattering line; a facility to handle transuranic, radioactive materials; soft x-ray lithography; ultraviolet and soft x-ray photoelectron spectroscopy systems with angle-integrated and angle-resolving capabilities; circular and magnetic circular dichroism; reflectance and absorption spectroscopies; and photon stimulated desorption.

Aladdin will operate—and Tantalus does operate—as a dedicated synchrotron source on a five day per week schedule with 48.5 h of beam time available for research. As with other national facilities, the user is responsible for the operation and the safety of his own instrumenation. The operation of the laboratory facilities is overseen by the SRC staff. The Physical Sciences Laboratory (PSL) of the University of Wisconsin provides the necessary support for the users, including computer capabilities (a VAX 11/780), purchasing services, mechanical and electrical engineering services, an outstanding machine shop, a library, and a stockroom. Housing is available at the PSL Guest House.

For additional information contact E. M. Rowe, Director, Synchrotron Radiation Center, 3725 Schneider Drive, Route 4, Stoughton, WI 53589.

E. NBS Synchrotron Radiation Facility, National Bureau of Standards, Gaithersburg, MD

The Synchrotron Ultraviolet Radiation Facility (SURF-II) at the National Bureau of Standards is a 280-MeV electron storage ring used as a dedicated light source in two areas of science: radiometry and experimental physics. Since the facilities for each of these two uses are for the most part independent, they are described separately.

The radiometric facilities fall into two classes: calibration and radiometric standards. SURF-II is an ideal light source for calibration since it is a single-magnet accelerator with a perfectly circular orbit. This feature allows the spectral distribution from the ring to be calculated with an accuracy of 2%. The calibration beam line consists of a white light port with accurate baffling to ensure a well-defined light beam. The beam light is equipped with a two-axis, two-transition gimbal on which a vacuum chamber or windowed instrument can be mounted. After an instrument is mounted, it is rotated about its entrance slit so that the light beam is scanned over its entire optical surface. For instruments which do not have their own vacuum envelope, e.g., rocket-borne or space-shuttle spectrometers, the beam line can be attached to a large vacuum chamber ($4 \times 4 \times 8$ ft) capable of attaining 10^{-8} Torr. A two-axis goniometer in the chamber again allows the mounted instrument to be rotated and the entire optical surface to be calibrated.

The radiometric standards beam line is used primarily for the calibration of photodiodes which are sold by NBS. It consists of a toroidal grating monochromator to disperse the light, a double ionization chamber to measure absolute photon intensity, and the diode chamber. Each diode is calibrated as a function of photon energy and is available as a secondary photometric standard. The calibration covers the photon energy range from 5 to 100 eV.

The facilities for experimental physics consist of three beam lines equipped with four monochromators. The first instrument is a high-flux, normal-incidence monochromator equipped with a differential pumping chamber to allow windowless gas-phase experiments. A pressure of 10^{-6} Torr can be maintained in the experimental chamber while the ring is operating. The spectral range is from 350 to 2000 Å, with a resolution of 0.05 Å. The maximum intensity is 10^{11} photons per second out of the exit slit.

The second instrument is a grazing-incidence, Rowland circle monochromator with an experimental chamber designed for reflectivity measurements. It covers the range from 80 to 800 Å, with a resolution of 0.15 Å. A gimbal in the experimental chamber allows a channeltron electron multiplier detector to be scanned about the sample.

The third monochromator has a range of 165 to 500 Å, with a resolution of 1 Å and an output of 10^{9} photons per second on the sample in a 2-mm-diam spot. A reentrant arrangement allows the sample to be placed within 2 cm of the slit. The experimental chamber contains a cylindrical mirror analyzer for surface-science studies. Both electron and ion emission from well-characterized surfaces can be studied.

The fourth monochromator is similar to the third one, but with a spectral range from 300 to 1000 Å. There is no permanent experimental chamber attached to it.

All these instruments are equipped with dedicated computers for experimental control and data acquisition.

Several monochromators are under construction. One is for a new radiometry facility which will also be available for experimentation. The second is a new high-flux, ultrahigh-vacuum monochromator to replace the surface-science facility. This instrument was being installed during the fall of 1983. Finally, a normal incidence monochromator with a resolving power of 10^{5} is scheduled to be in operation by the summer of 1984.

For additional information contact R. P. Madden, or D. L. Ederer, National Bureau of Standards, Washington, DC 20234.

III. FACILITIES FOR MICROANALYSIS, MICROFABRICATION, AND SURFACE STUDIES

The five facilities described in this section provide a great variety of sophisticated devices for probing, characterizing, and altering the structures of materials, and for preparing new materials and new structures. Surfaces and microstructures command a large share of the effort. It is worth noting that these facilities allow numerous powerful techniques to be brought to bear simultaneously on a single problem.

Figure 2 shows a small section of an array of resonant elements—dipole openings in a gold film deposited on calcium fluoride—fabricated at NRRFSS (see Sec. A below). The array acts as a band rejection transmission filter in the mid-infrared (7–9 μ). The primary resonant frequency is one-hundred times higher than any previously reported.

A. National Research and Resource Facility for Submicron Structures, Cornell University, Ithaca, NY

In 1977 the National Science Foundation established a National Research and Resource Facility for Submicron Structure (NRRFSS) to help advance submicron science and technology. The specific objectives of NRRFSS are: (1) to promote and carry out research to advance the art of submicron fabrication technology, and to train scientists and engineers in this field; (2) to provide a resource primarily for use by the university community to fabricate advanced devices or research structures which require submicron dimensions; (3) to stimulate innovative research outside the electrical engineering device community which will shed light on fundamental physics or materials problems limiting submicron technology; and (4) to keep the technical community informed on progress at the Facility.

Microfabrication research at NRRFSS involves about one hundred Cornell graduate students representing about eight departments and thirty-five faculty members. In addi-

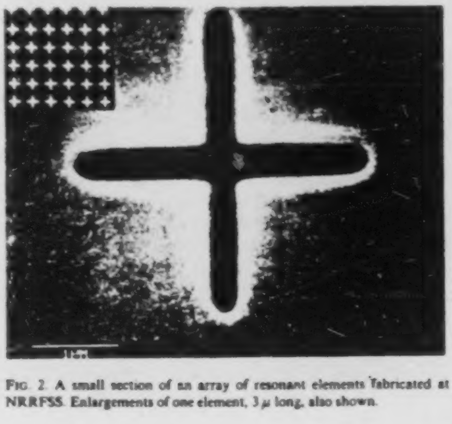


FIG. 2. A small section of an array of resonant elements fabricated at NRRFSS. Enlargements of one element, 3 μ long, also shown.

tion there are currently about thirty approved user projects outside Cornell. The Cornell research includes both facility development research and user research. The facility development research emphasizes enhancement of equipment and techniques in advanced lithography and dry pattern transfer processing as well as thin-film growth, deposition, and modification and, to a lesser extent, advanced device technologies and thin-film electrical, chemical, and structural analysis. Both facility development research and user research projects are initiated by a proposal review process.

For additional information contact E. D. Wolf or R. A. Brown, NRRFSS, Knight Laboratory, Cornell University, Ithaca, NY 14853.

B. The Center for Microanalysis of Materials, University of Illinois, Urbana, IL

It is not possible for an individual group to support equipment and maintain an interest in all of the techniques of microanalysis. The result is that, in general, a research group specializes in a particular characterization technique and tailors its research to it. The University of Illinois has adopted a different approach: instrumentation for microcharacterization of materials has been gathered into the Center for Microanalysis of Materials that operates as a facility for all of the materials research programs on campus and many collaborative research programs with other universities and laboratories.

The Center has transmission electron microscopes, scanning electron microscopes, a scanning transmission electron microscope, electron microprobes, scanning Auger microscopes, secondary ion microprobes, an x-ray photoelectron spectroscopy unit, rotating and fixed anode x-ray sources fitted with instrumentation for EXAFS, topography, small-angle scattering and all standard x-ray methods, and an accelerator for backscattering spectroscopies. Most of these instruments are modern commercial machines fitted with a wide range of accessories and instrumentation. In addition the Center has extensive facilities for specimen preparation. The Center is operated by a staff of about a dozen professionals/academics who guide and collaborate in research, maintain the equipment, and give instruction for its use.

More than a hundred faculty members on the University of Illinois campus carry out research in materials science. The Center for Microanalysis of Materials provides them with the unique opportunity to use almost any microanalytical technique, or combination of techniques, to characterize their samples.

A flexible program of interaction with other institutions is also maintained. For additional information contact J. A. Eades, Materials Research Laboratory, University of Illinois, 104 S. Goodwin, Urbana IL, 61801.

C. ORNL Surface Modification and Characterization Collaborative Research Center, Oak Ridge, TN

The Oak Ridge National Laboratory Surface Modification and Characterization Collaborative Research Center (SMAC) is a facility for cooperative research involving university and industrial scientists working with ORNL personnel on problems of mutual interest. The goal of the center is to provide and maintain advanced processing and characterization techniques for *in situ* alteration and analysis of near-surface properties of a wide range of materials.

The materials processing capabilities of the Center feature ion implantation doping, ion beam and laser mixing, and pulsed-laser processing. These are all nonequilibrium processing techniques capable of achieving new and often unique materials alterations not possible with equilibrium processing methods. The *in situ* materials characterization capabilities emphasize ion scattering and nuclear reaction analysis, ion channeling, surface analysis techniques (LEED, Auger, etc.), and other property measurements such as electrical resistivity and optical reflectivity.

The SMAC facility is equipped with beam lines from positive-ion analysis accelerators and a high-current ion implantation accelerator integrated into common ultra-high-vacuum chambers (10^{-10} Torr) which contain surface analysis instruments, solid-state detectors, and UHV goniometers and sample holders, as well as optical windows which allow *in situ* laser processing. With these facilities it is possible to alter materials properties in UHV by ion beam and laser processing at sample temperatures from 4 to 1,300 K, and to analyze the materials in place. The ion accelerators include a 2.5-MeV Van de Graaf, a 200-keV high-current implantation accelerator, and a 1.7-MeV tandem accelerator, with both duoplasmatron and heavy-ion sources. The latter is scheduled for operation in 1984. A wide range of high-powered lasers is available, including ruby, Nd:Yag, and KrF lasers (15×10^{-9} s pulse duration time); a mode-locked Nd:Yag laser (30×10^{-12} s pulse duration time); and a cw Ar ion laser. With these laser sources it is possible to achieve heating and cooling rates that vary from approximately 10^6 to approximately 10^{12} °C per second in the near-surface region.

Facilities in the Center are being expanded to accommodate more users. For additional information contact B. R. Appleton, Solid State Division, ORNL, Oak Ridge, TN 37830.

D. SHaRE Program, Oak Ridge National Laboratory, Oak Ridge, TN

The SHaRE Program is a collaborative research venture in materials science between the research staff of ORNL and the research staff at both universities and industrial laboratories. Managed by Oak Ridge Associated Universities, its purpose is twofold: (1) to permit ORNL research staff members to carry out additional research relevant to the Department of Energy programs that would not ordinarily be possible; and (2) to make available to university staff and industrial researchers sophisticated research equipment at ORNL which is not available in their home institutions.

All research sponsored at ORNL under the SHaRE program is collaborative, with at least one ORNL staff member and one senior researcher from the outside institution having joint responsibility for successful completion of each project and for publication of the work.

From its inception in late 1978, the SHaRE program has concentrated on the application of advanced microanalytical techniques to research areas in materials science. Centered in the Metals and Ceramics Division, the facilities used under the SHaRE program include the analytical electron microscopes, the high-voltage electron microscope facility, the Auger electron spectrometry/surface microanalytical apparatus, the Van de Graaf nuclear backscattering equipment, and the computer facilities. Once a project is established as a collaborative SHaRE program, there is no charge for the use of the facilities. Access to the program requires submission of a proposal which involves an interested ONRL collaborator.

For additional information contact E. A. Kenik, Metals and Ceramics Division, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, TN 37830.

E. Regional Instrumentation Facility (CRISS), Montana State University, Bozeman, MT

The regional Instrumentation Facility at the Montana State University Physics Department (CRISS: Center for Research in Surface Science and Submicron Analysis) is devoted principally to basic and applied research in surface physics and chemistry. The main instrumentation includes: (1) a scanning Auger microprobe; (2) a high-resolution electron-energy-loss spectrometer with double-pass monochromator and analyzer; and (3) an ESCA system with Al/Mg double-anode x-ray head and hemispherical analyzer; the ESCA system is housed in the same vacuum as (2).

A singular advantage of this arrangement is the possibility of doing ELS and ESCA experiments in conjunction. The ESCA analyzer can do ion scattering spectroscopy in conjunction with the ion gun. The chamber supports a SIMS add-on based on a quadrupole mass analyzer. A third vacuum chamber supports a low-resolution (5-μ beam size) scanning Auger spectrometer and a He-discharge lamp for Ultraviolet Photoemission Spectroscopy. The laboratory also has the usual support facilities.

Although the advice and assistance of the staff are available to whatever extent necessary for effective execution of the experiments, the laboratory is operated primarily as a user facility, and the users are expected to plan and execute their own experiments, devoting the necessary time (from 1 to 3 days) to learn the operation of the equipment. The user's stay at the facility is generally from one to three weeks.

The staff includes a director, two staff scientists, a technician, and an administrative assistant. For additional information contact G. J. Lapeyre, Physics Department, Montana State University, Bozeman, MT 59717.

IV. ELECTRON MICROSCOPES

High voltage and ultrahigh resolution in electron microscopy require large installations. The three installations described here provide advanced capabilities for users. An example of the work is shown in Fig. 3, which is a micro-

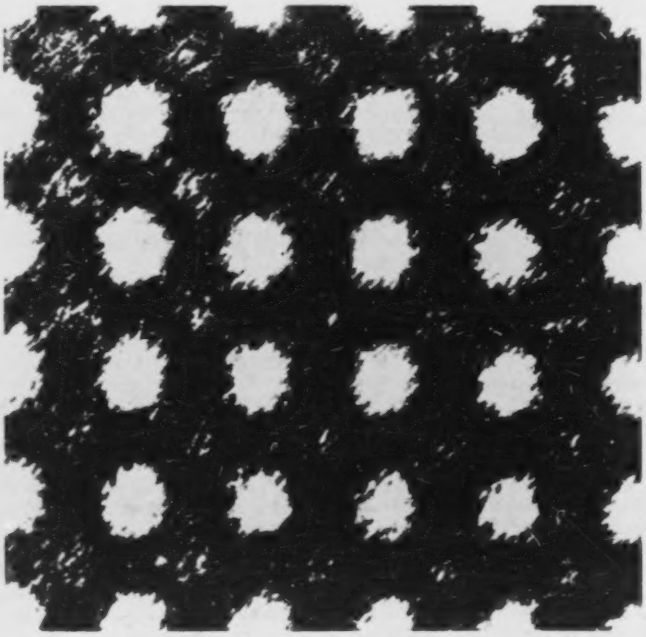


FIG. 3. Micrograph of zirconium dioxide with atomic resolution, taken on the JEM ARM-1000 at the National Center for Electron Microscopy.

graph of zirconium dioxide with atomic resolution. All atomic positions in a (0 0 1) projection are shown. The photograph was taken on the JEM ARM-1000 at the National Center for Electron Microscopy.

A. Facility for High Resolution Microscopy, Arizona State University, Tempe, AZ

The Facility for High Resolution Microscopy in the Center for Solid State Science at the Arizona State University is supported by the National Science Foundation and the State of Arizona. The goals of the Facility are to advance the methods and instrumentation of electron microscopy; to apply new research methods to the structural analysis of solids, particularly in the areas of materials science, solid-state physics, solid state chemistry, and geology; and to provide high-resolution research facilities for use of scientists and engineers from the solid-state science community at large. In addition, the Facility conducts topical research conferences and advanced electron microscopy schools each January.

The principal research topics of current interest are high-resolution imaging of surfaces and interfaces, electron-loss spectroscopy, microdiffraction, and energy dispersive x-ray spectroscopy. There are, at present, six electron microscopes at the facility, including two field-emission-source instruments (EM400/ST and HB-5) and a fixed-beam imaging instrument with 2.5-Å resolution. The field-emission-source instruments have been shown capable of high coherent microdiffraction from specimen areas as small as 5 Å, and microspectroscopy from areas about 10 Å in diameter. These experimental methods are being applied to an increasing number of intriguing problems, particularly in the areas of electronic materials, surfaces, and catalysts.

During the last year, more than twenty outside scientists conducted research at the Center with the assistance of an on-site support staff, and about forty on-site research programs made use of the Facility.

The topic of the January 1983 Research Conference at the Facility was High Resolution Imaging and Microanalysis of Surfaces. The conference topic for January 1984 is High Resolution Structural and Chemical Analysis of Boundaries and Interfaces.

For additional information contact the Director, Facility for High Resolution Electron Microscopy, Center for Solid State Science, Arizona State University, Tempe, AZ 85287.

B. National Center for Electron Microscopy, Lawrence Berkeley Laboratory, Berkeley, CA

The National Center for Electron Microscopy (NCEM) is primarily a high-voltage electron microscope facility with instrumentation designed for ultrahigh resolution or dynamic *in situ* imaging of materials. The Center is supported by the U. S. Department of Energy, and its instruments have been designated as user facilities.

Among the unique microscopes in the NCEM is a Kratos EM-1500, the only instrument in the U. S. which provides accelerating voltages in the 1200–1500-kV range. It features both a top-entry goniometer stage for high-resolution work and a side-entry stage for dynamic *in situ* and environmental cell studies. Depending upon the choice of specimen holder, the sample can be viewed over a plus or minus 45 deg tilt angle, at temperatures ranging from ambient to 850 °C and with various gaseous environments up to 1 atm pressure. Dynamic events can also be recorded on video tape. The operating pressure in the optical column can be brought to 10^{-7} Torr and the microscope has demonstrated a point-to-point resolution of about 3 Å.

A second instrument is the JEM ARM-1000, the only instrument of its kind in the world, providing a point-to-point resolution of 1.7 Å or better over all operating voltages up to 1000 kV. It has a top-entry goniometer stage with 45 deg biaxial tilting and height adjustment which, in addition to variable focal length, enables convergent beam electron diffraction patterns to be taken from the same specimen areas imaged in high resolution. Operating pressures are in the 10^{-8}-Torr range. The microscope makes extensive use of microprocessor control for precise operation, and has very high brightness (10^8 A/cm^2 ster) due to its lanthanum hexaboride filament design.

Other microscopes within the NCEM include a JEOL JEM 200CK with an ultra-high-resolution goniometer and a Hitachi HU-650 high-voltage electron microscope with hot stage and environmental cell. By September 1983 a new building addition should have been completed to house the remainder of the NCEM support equipment, including wet and dry specimen preparation laboratories, optical diffractometer, image analysis and processing hardware, and an on-site minicomputer-based image simulation laboratory to assist with micrograph interpretation.

Beam time of the NCEM microscopes is allocated after review and acceptance of research proposals submitted in advance. In accordance with Department of Energy policy, as long as the proposed work is of documented programmatic interest to the Department and the results are published in the open literature, there is no charge for use of the NCEM microscopes.

For additional information contact G. Thomas, Scientific Division, or K. H. Westmacott, Materials and Molecular Research Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720.

C. HVEM-Tandem-Accelerator National User Facility at Argonne National Laboratory, Argonne, IL

The High Voltage Electron Microscope (HVEM)-Tandem Facility is a unique national research facility. It is supported by the U. S. Department of Energy and is available to scientists from industry, universities, and other national laboratories, after approval of submitted research proposals. The facility is operated by the Materials Science and Technology Division of ANL and provides a unique combination of capabilities for high-voltage electron microscopy, ion implantation/bombardment, and ion beam analysis. A number of side-entry stages permits *in situ* experiments in the temperature range from 10 to 1300 K *in vacuo*, and from ambient to 1300 K in noncorrosive gaseous atmospheres. Straining stages are available for deformation and fracture studies over a wide range of experimental conditions. The

HVEM/ion beam interface permits direct observation of the effects of electron and ion bombardment on materials in the microscope. The ion beam interface may be used with either a 300-kV ion accelerator or the 2-MV tandem ion accelerator. Calibrated dosimetry systems are available for both ion and electron beams.

Prime-time usage of the facility is divided approximately equally between ANL and non-ANL scientists. The facility staff is available during one or two shifts a day to instruct experimenters in the use of the equipment, and in some intances to participate in experimental programs. In general researchers are expected to become competent to operate the equipment. A course of lectures on high-voltage microscopy supplemented by lecture notes is available on video tape.

When not scheduled for use with the HVEM the 2-MV Tandem and the 300-kV accelerators are used separately from the microscope by the ANL staff. Outside users wishing to use the accelerators alone are requested to collaborate with the appropriate group of the Materials Science and Technology Division of ANL.

For additional information contact the Facility Secretary, Sheryl Ruffatto, Building 212, Argonne National Laboratory, Argonne, IL 60439.

V. OTHER FACILITIES

This section lists several facilities that do not fit in the foregoing categories. They are the Francis Bitter National Magnet Laboratory, which provides ultrahigh magnetic fields of various kinds; the Los Alamos Equation of State Library, which provides the latest information on matter under extremes of pressure and temperature; and the Combustion Research Facility, which provides powerful new capabilities for the study of combustion in engines and other systems.

A. The Francis Bitter National Magnet Laboratory, M.I.T., Cambridge, MA

The Francis Bitter National Magnet Laboratory is the largest facility in the world for generation of intense continuous magnetic fields. The Laboratory traces its origin to the work of Prof. Francis Bitter, who pioneered electromagnetic technology in the 1930's; it was organized as a national laboratory in 1960 and started its operation at the present site in 1963. The National Science Foundation has been sponsoring the Laboratory's operation since 1970.

The Magnet Laboratory's facilities are available to users free of charge. A variety of high-field magnets are provided, together with cryogenic measurement and data processing equipment. Experienced support staff is also available on a full-time basis to assist visitors with all aspects of their experiments. Research staff at the Laboratory can be consulted about problems in specialized areas.

The Laboratory features almost two dozen water-cooled (Bitter) magnets in five bore diameters from 3.3 to 24.8 cm, with fields as high as 25 T in a 5.4-cm bore and 30 T in a 3.3-cm bore.

All fields are calibrated to 0.1% and are repeatable and stable to 0.05% short term, and 0.1% long term. Time stability of a few parts in 100 000 can be obtained with a localized feedback system. This system makes it possible, for example, to do nuclear-magnetic-resonance experiments in spatially uniform fields and to reduce eddy-current heating in low-temperature experiments. At the other extreme, modulation fields of up to 0.5 T peak-to-peak at 7.5 Hz can be generated for use with ac signal processing in, for example, quantum oscillatory experiments. The dc fields can be swept continuously from zero to maximum in as little as 1 min or as much as 2 h. Field setting, sweep, and modulation are all under local control by the user.

Two new sets of magnets should become available soon: (1) a pulsed-field facility which offers fields up to 45 T with 10-ms duration in a 1-cm bore at 4.2 K (1.5-cm bore at 77 K); (2) a superconducting magnet with a 20-min sweep to a 15-T field and a 5-cm room temperature access.

Users have available to them a broad range of equipment and apparatus, including complete temperature control systems with a range from 1.5 to 300 K, helium-3 and dilution refrigerators, and a complete de Haas—van Alphen apparatus along with homogeneous fields up to 24 T.

There is a queue of approximately three months for reserved magnet time—which is assigned in blocks of 15 to 30 h, depending on the power required. First-time users, however, can usually be accommodated within several weeks, and all users have the option of requesting magnet time on a recurring, biweekly basis. There is a separate queue for the use of the hybrid magnets.

For additional information contact Larry Rubin, Francis Bitter National Magnet Laboratory, NW-1108, M. I. T., Cambridge, MA 02139.

B. The Los Alamos Equation-of-State Library (SESAME), Los Alamos National Laboratory, Los Alamos, NM

The SESAME Equation-of-State (EOS) Library is a standardized, computer-based library of tables of thermodynamic properties and FORTRAN subroutines developed and maintained by the Equation-of-State and Opacity Group of the Theoretical Division of Los Alamos National Laboratory.

The Library contains data for about 70 materials, including metals, minerals, polymers, mixtures, etc., as well as simpler atomic and molecular species. The Library is being offered to all interested users free of charge.

The thermodynamic data stored in the Library include tables of pressure P and energy E (and also, in some cases, of Helmholtz free energy A), each as a function of density and temperature. Besides total P, E, and A tables, in many cases separate tables of thermal, electronic, and ionic (including zero point) contributions to P, E, and A are available. The SESAME EOS Library also has opacity data with a low-temperature limit of about 1 eV.

For further information on the SESAME EOS Library, write to SESAME Library, T-4, MS B925, Los Alamos National Laboratory, Los Alamos, NM 87545. Users interested in the opacity data should contact A. L. Merts or M. F. Argo, T-4, MS B212, Los Alamos National Laboratory, Los Alamos, NM 87545.

C. Combustion Research Facility, Sandia National Laboratories, Livermore, CA

The Combustion Research Facility (CRF) at Sandia National Laboratories in Livermore provides scientists an opportunity to study all phases of combustion science and technology. Researchers from universities, industry, and other government laboratories are encouraged to use the many laboratory and computer facilities, and to collaborate with resident scientists studying the basic chemistry and fluid mechanics of flames, as well as combustion phenomena occurring in devices such an engines and coal combustors. Central to nearly all CRF research is the incorporation of the most advanced laser-based techniques, many of which are being developed at the facility.

One part of this program is supported by the Division of Materials Sciences, Office of Basic Energy Sciences, U. S. Department of Energy, to develop a better understanding of the degradation of ceramic coatings and metallic alloys in the hot, corrosive, particulate-laden environments often present in combustion systems. Here, too, the application of the latest optical techniques has been strongly emphasized. Examples of such techniques, which are either in development or in use to study relevant problems, are:

(1) *In situ* surface Raman spectroscopy, which provides nonintrusive, real-time measurements of the chemical compositions and structural phases of corrosion layers building up on the surfaces of exposed materials.

(2) Raman microscopy, wherein Raman spectra are obtained with 1-μ resolution for the detailed characterization of polycrystalline or amorphous materials typical of most corrosion layers.

(3) Sputter-induced photon spectroscopy, in which optical emissions from excited atoms sputtered from surfaces provide high sensitivity for detecting trace species, including hydrogen, in insulating as well as conducting materials.

(4) Sputter-Raman spectroscopy, in which Raman spectroscopy is used to determine the depth profile of corrosion layers as material is removed by sputtering.

For additional information contact Walter Bauer, Department 8340, Sandia National Laboratories, Livermore, CA 94550.

PRICING AND ORDERING INFORMATION FOR USER FACILITIES RERINTS

PRICES: $5.00; $4.50 each for bulk orders of ten or more copies of the same article sent to one address. Delivery is via surface mail. Airmail delivery available at the following surcharge: $2.50 for the first copy plus $1.00 for each additional copy sent to one address. *Reprint orders must be prepaid.*

ORDERS: Please specify REV. SCI. INSTRUM. USER FACILITIES and give the article title, authors, month, and year of publication, and the page number of the article's title page. Send orders accompanied by payment in full (make checks payable to American Institute of Physics) to: *Current Physics Reprints, American Institute of Physics, 335 East 45th Street, New York, NY 10017.*

APPENDIX B

REFERENCES AND RELATED LITERATURE

1. NRC Solid State Sciences Committee, *An Assessment of the National Need for Facilities Dedicated to the Production of Synchrotron Radiation*, National Academy of Sciences, Washington, D.C., 1976.

2. NRC Solid State Sciences Committee, *Neutron Research on Condensed Matter: A Study of the Facilities and Scientific Opportunities in the United States*, National Academy of Sciences, Washington, D.C., 1977.

3. NRC Solid State Sciences Committee, *High-Magnetic-Field Research and Facilities*, National Academy of Sciences, Washington, D.C., 1979.

4. NRC Solid State Sciences Committee, Subcommittee on Free Electron Laser, *The Free Electron Laser*, National Academy Press, Washington, D.C., 1982.

5. NRC Solid State Sciences Committee, Subcommittee on Synchrotron Radiation Facilities, *Current Status of Facilities Dedicated to the Production of Synchrotron Radiation*, D. W. Lynch, ed., National Academy Press, Washington, D.C., 1983.

6. Ames Laboratory, *Report of the Review Panel on Neutron Scattering*, IS-4761, Ames, Iowa, October 1980.

7. NRC Solid State Sciences Committee, Panel on Neutron Scattering, *Current Status of Neutron-Scattering Research and Facilities in the United States*, National Academy Press, Washington, D.C., 1984.

8. National Synchrotron-Radiation Planning Committee, *Planning Study for Advanced National Synchrotron-Radiation Facilities*, Sandia National Laboratories, Albuquerque, NM, 14 March 1984.

9. D. Allan Bromley, "Neutrons in Science and Technology," *Physics Today*, Vol. 36, No. 12, 30-39, December 1983.

10. Remarks by Dr. George A. Keyworth, "Materials Research: A Model for Improved University/Industry Cooperation," Address to Materials Research Society, Boston, MA, Office of Science and Technology Policy, Washington, D.C., 14 November 1983.

11. National Science Foundation, "Workshop on a National Facility for the Study of Heterogeneous Catalysis," Division of Chemical and Process Engineering, National Science Foundation, Washington, D.C., 8-9 May 1981.

12. U.S. Department of Energy, Report of the 1983 HEPAP Subpanel on New Facilities for the U.S. High Energy Physics Program, DOE/ER-0169, Washington, D.C., July 1983.

13. NRC Astronomy Survey Committee, Astronomy and Astrophysics for the 1980's: Vol.1: Report of the Astronomy Survey Committee, Chapter 2, National Academy Press, Washington, D.C., 1982.

14. Energy Research Advisory Board, Materials R&D Panel, Materials Research and Development, DOE/S-0027, Energy Research Advisory Board, Washington, D.C., November 1983.

15. DOE/NSF Nuclear Science Advisory Committee, A Long Range Plan for Nuclear Science, U.S. Department of Energy, Washington, D.C., December 1983.

16. NRC Solid State Sciences Committee, Panel on Support of Small Research Projects in Materials Sciences at Universities, Support of Small Research Projects in Materials Sciences at Universities, National Academy of Sciences, Washington, D.C., 1979.

17. H. Winick, G. Brown, K. Halbach, and J. Harris, "Wiggler and Undulator Magnets," Physics Today, Vol. 34, No. 5, 50-63, May 1981.

18. J. Spencer and H. Winick, in Synchrotron Radiation Research, H. Winick and S. Doniach, eds., Plenum Press, NY, 1980, p. 663.

19. A. Hoffman, "Synchrotron Radiation From The Large Electron-Positron Storage Ring," Physics Reports, Vol. 64, 253-281, 1980.

20. E. E. Koch, ed., Handbook of Synchrotron Radiation, Vol. I, parts A and B, North-Holland, Amsterdam, 1983.

21. NRC Solid State Sciences Committee, Subcommittee on Muon Sources for Solid State Research, Muon Sources for Solid-State Research, National Academy Press, Washington, D.C., 1984.

22. George H. Vineyard and L. M. Falicov, "National Facilities for Research in the Physics of Condensed Matter," Review of Scientific Instruments, Vol. 55, No. 4, 620-630, April 1984.

23. An Assessment of the Needs for Equipment, Instrumentation, and Facilities for University Research in Science and Engineering, National Academy of Sciences, Washington, D.C., 1971.

24. Division of Science Resources Studies, Science Resources Studies Highlights, One-fourth of Academic Research Equipment Classified Obsolete, National Science Foundation, Washington, D.C., 1984.

25. D. M. Mills, A. Louis, A. Harootunian, J. Huang, and B. Smith, "Time-Resolved X-ray Absorption Spectroscopy of Carbon Monoxide-Myoglobin Recombination After Laser Photolysis," Science, Vol. 223, No. 4638, 811-813, 24 February 1984.

26. D. M. Mills, "Time-Resolution Experiments Using X-ray Synchrotron Radiation," Physics Today, Vol. 37, No. 4, 22-30, April 1984.

27. K. J. Kim, K. Halbach, and D. Attwood. Proceedings of the Second Topical Meeting on Laser Techniques in the Extreme Ultraviolet, Boulder, 3-7 March 1984 (to be published).

APPENDIX C

PRESENTATIONS TO THE MAJOR MATERIALS FACILITIES COMMITTEE

CONTENTS

FOREWORD

I. WORKSHOP: MARCH 17-19, 1984*

A. INTRODUCTION

Probing Matter with Electrons, Neutrons, and Photons
J. D. Litster, Massachusetts Institute of Technology

B. SCIENTIFIC OPPORTUNITIES WITH SYNCHROTRON RADIATION
D. W. Lynch, Iowa State University, Chairman

1. X-Ray Physics
   D. E. Moncton, Brookhaven National Laboratory
2. Scientific Opportunities with Vacuum Ultraviolet (Soft X-Ray) Synchrotron Radiation from Insertion Devices
   J. Stohr, Exxon Research & Engineering Company
3. X-Ray Microprobe Characterization of Materials: The Case for Undulators on Advanced Storage Rings
   C. J. Sparks, Jr., Oak Ridge National Laboratory
4. Synchrotron Radiation Research in Biology and Medicine
   K. Hodgson, Stanford University

C. SCIENTIFIC OPPORTUNITIES WITH NEUTRONS
R. J. Birgeneau, Massachusetts Institute of Technology, Chairman

1. Physics
   J. D. Axe, Brookhaven National Laboratory
2. Chemistry
   B. Fender, Institut Laue-Langevin

---

* S. A. Rice, University of Chicago, and J. D. Litster, Massachusetts Institute of Technology, served as Co-Chairmen of a panel discussion on March 17.

3. Scientific Opportunities with Neutrons in Materials Science
   J. R. Weertman, Northwestern University
4. Application of Neutron Beam Research in Biology and Medicine
   P. B. Moore, Yale University

D. OVERVIEW OF RELATED REPORTS

1. Current Status of Neutron Scattering Research and Facilities the United States
   S. A. Werner, University of Missouri
2. Planning Study for Advanced National Synchrotron Radiation Facilities
   M. L. Knotek, Sandia National Laboratories

E. PROPOSED NEW AND UPGRADED FACILITIES FOR SYNCHROTRON RADIATION RESEARCH
   D. W. Lynch, Iowa State University, Chairman

1. Prospectus for a 6 GeV Synchrotron Source, Argonne National Laboratory
   Presented by K. L. Kliewer
2. Planned Evolution of the NSLS, Brookhaven National Laboratory
   Presented by D. E. Moncton
3. A Prospectus for a 6 GeV Dedicated Synchrotron Radiation Facility at Cornell University, Cornell High Energy Synchrotron Source
   Presented by B. D. McDaniel
4. The Advanced Light Source: Scientific Opportunities, Lawrence Berkeley Laboratory
   Presented by H. Grunder
5. SSRL's Planning for a New Synchrotron Radiation Facility including a 6 GeV Storage Ring, Stanford Synchrotron Radiation Laboratory
   Presented by A. I. Bienenstock and H. Wiedemann

F. PROPOSED NEW AND UPGRADED FACILITIES FOR NEUTRON SCATTERING
   R. J. Birgeneau, Massachusetts Institute of Technology, Chairman

1. The Argonne Neutron Plan, Argonne National Laboratory
   Presented by G. H. Lander
2. Guide Hall at the High Flux Beam Reactor, Brookhaven National Laboratory
   Presented by B. P. Schoenborn
3. WNR/PSR Experimental Hall Expansion, Los Alamos National Laboratory
   Presented by J. C. Browne

4. NBS Center for Cold Neutron Research, National Bureau of Standards
   Presented by J. M. Rowe
5. ORNL Presentation to the Major Materials Facilities Committee of the National Research Council, Oak Ridge National Laboratory
   Presented by R. M. Moon

G. THE ROLE OF NATIONAL LABORATORIES IN MATERIALS RESEARCH

1. The Role of National Laboratories in Materials Science Research
   H. Postma, Oak Ridge National Laboratory
2. Synchrotron R&D at the Defense Programs Laboratories
   P. E. Coyle, Lawrence Livermore National Laboratory
3. Overview of the Recent ERAB Report on Materials Research and Development
   R. H. Pry, Gould, Inc.

II. COMMITTEE MEETING MAY 3, 1984

OTHER KINDS OF MAJOR MATERIALS FACILITIES
A. Narath, AT&T Bell Laboratories, Chairman

1. High Magnetic Field Research in the U.S. - Status of the National Facility and Future Opportunities
   P. A. Wolff, Massachusetts Institute of Technology
2. The Materials Research Laboratory Program
   W. D. Nix, Stanford University
3. Toward an Advanced Materials Processing and Analysis Center (AMPAC)
   H. K. Bowen, R. M. Latanision, and J. B. Vander Sande, Massachusetts Institute of Technology

III. LIST OF RELEVANT REPORTS

IV. PARTICIPANTS AT THE WORKSHOP, COMMITTEE, AND PANEL MEETINGS

V. CORRESPONDENTS

APPENDIX D

PRESENTATIONS TO PANELS OF THE MAJOR MATERIALS FACILITIES COMMITTEE

Neutron Scattering Panel

National Academy of Sciences, Washington, D.C.
February 26-27, 1984

Argonne National Laboratory: R. Kustom, G. Lander
Brookhaven National Laboratory: V. Emory, B. Schoenborn
Los Alamos National Laboratory: J. Browne, R. Silver
National Bureau of Standards: M. Rowe, C. Han
Oak Ridge National Laboratory: H. Mook, R. Moon, Jr.
Department of Energy Perspective: L. Ianniello
National Bureau of Standards Perspective: R. Kammer

Synchrotron Radiation Panel

Molecular Biology Institute
University of California at Los Angeles
February 28, 1984

A 1.6 GeV Storage Ring: D. Shirley, D.Attwood, Lawrence Berkeley Laboratory
A 6 GeV Storage Ring*: A. Bienenstock, H. Wiedemann, Stanford Synchrotron Radiation Laboratory; D. Mills, B. Battermann, Cornell High Energy Synchrotron Source; M. Blume, S. Krinsky, Brookhaven National Laboratory; K. Kliewer, Y. Cho, Argonne National Laboratory

* The speakers shared the time describing science for a 6 GeV machine; each devoted a modest fraction of his presentation to site-specific plans.

Other Specialized Facilities Panel

National Academy of Sciences, Washington, D.C.
March 8, 1984

UV Laser Sources: G. Rosenblatt, Los Alamos National Laboratory
National Magnet Laboratory: P. Wolff, Massachusetts Institute of Technology
Muon Sources: R. H. Heffner, Los Alamos National Laboratory

DOE/S-0037

REVIEW OF THE NATIONAL RESEARCH COUNCIL REPORT "MAJOR FACILITIES FOR MATERIALS RESEARCH AND RELATED DISCIPLINES"

Prepared by the Materials Ad Hoc Review Panel

June 1985

A Report of the
Energy Research Advisory Board
to the
United States Department of Energy
Washington, D.C. 20585

Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington D.C. 20585
(202) 252-8933

The Honorable John S. Herrington
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, D.C. 20585

Dear Mr. Secretary:

I am pleased to forward to you the Energy Research Advisory Board's review on "Major Facilities for Materials Research and Related Disciplines." This review was undertaken in response to Secretary Hodel's request of July 2, 1984 to review four studies being carried out under the auspices of the National Research Council (NRC) that address the contributions and future potential of various areas of science and engineering. This review is the first such assessment. The others will be done when the relevant NRC studies are completed.

The NRC study on major materials facilities sought to prioritize the various proposed facilities in terms of their importance to science. The ERAB review has undertaken, as requested, to assess the recommended facilities in terms of the Department's programs and responsibilities. Our general finding is that the recommended facilities are needed and will make an important contribution to continuing the nation's scientific and technological leadership. It is also quite clear that in most instances the Department of Energy is the appropriate locus in the government to address these needs. A phased approach is recommended that would spread the costs over roughly a decade. While we believe that the needed incremental funding should be attainable within the overall flexibility of the Department we do not feel it appropriate for the Board to involve itself in the specifics of the budget. The Board would be concerned, however, if funding levels became so constrained that existing facilities are operated unproductively or individual research projects are curtailed.

It is of particular importance for the major new facilities that a soundly conceived program of pre-construction R&D be carried out prior to a commitment to build the facility. We believe that such a phase is needed even for the proposed 1-2 GeV synchrotron on which considerable design effort has already been expended. This need is underscored by the difficulties that have led the National Science Foundation to terminate efforts to construct a synchrotron facility at the University of Wisconsin. The failure of that project to proceed makes the proposed DOE synchrotron project more urgent. However, it is equally important that the project be carried out with a solid knowledge of cost, schedule and anticipated performance.

The report also recommends that DOE take the lead in initiating a "shared advisory and decision process" among the agencies that are involved in materials research. In the course of discussing this recommendation it became clear that many ERAB members feel that the government agencies have far too little input from private industry in the formulation of their programs. Therefore, if an advisory structure is established to deal with materials facilities or with materials research more broadly, a strong component of industry participation should be included.

Throughout the course of this review we received assistance and input from DOE Laboratories, other government agencies and staff of the Office of Energy Research, all of whom were cooperative and helpful.

I hope that you will find this report useful and I will be happy to discuss it with you or your staff at your convenience.

Sincerely,

Ralph S. Gens

Ralph S. Gens
Chairman

The
University of Oklahoma

COLLEGE OF GEOSCIENCES
Office of the Dean
601 Elm Street, Room 438
Norman, Oklahoma 73019
(405) 325-3101

April 16, 1985

Mr. Ralph Gens, Chairman
Energy Research Advisory Board
4046 S.W. Jerald Court
Portland, Oregon 97221

Dear Ralph,

In September, you requested that Arthur Hansen select a subgroup of his panel on Long-Range Research to provide an ad hoc review of the NAS Seitz-Eastman Report on Major Facilities for Materials Research and Related Disciplines. This subgroup was charged to review each recommendation of the Seitz-Eastman Report (hereafter called the S&E Report) and to recommend an appropriate DOE action in terms of: 1) DOE programmatic interests, 2) overall importance to the nation, 3) budgeting considerations of cost and time, and 4) urgency of action and overall priorities.

The requested Ad Hoc Review Committee was assembled and consisted of: Frank Stebli, Chairman; Arthur Hansen; John Huizenga; and Robert Fry (all of ERAB); and, additionally, of Walter Brown, AT&T Bell Labs; Richard Claassen, Sandia-Livermore Laboratories; Edward Knapp, Los Alamos; and Ralph Simmons, University of Illinois. This group has attempted to examine the nationally oriented S&E Report in terms of events subsequent to its release and in terms of the DOE mission, including its weapons mission and to consider also the national need for accelerator- and reactor-based materials research facilities which only DOE can provide. The group also considered timing, budget and operational matters and makes some recommendations on these subjects.

The Review Committee would appreciate it if the enclosed report could be brought before ERAB at its May meeting.

Sincerely,

Frank

Francis G. Stebli, Chairman
Materials Facilities
Ad Hoc Review Committee

FGS/jr
Enclosure

c: Tom Kitchens
Charles Cathey
Arthur Hansen
Ralph Simmons
John Huizenga
Robert Fry
Edward Knapp
Walter Brown
Richard Claassen

June 1985

ENERGY RESEARCH ADVISORY BOARD

Ralph S. Gens, Chairman
Consulting Engineer

Betsy Ancker-Johnson
Vice President
Environmental Activities Staff
General Motors

Frank Baranowski
Consultant

Ivan L. Bennett, Vice Chairman
Professor of Medicine
New York University Medical Center

Melvin Calvin
Professor of Chemistry
Department of Chemistry
University of California

William D. Carey
Executive Officer
American Association for the
Advancement of Science

Floyd L. Culler, Jr.
President
Electric Power Research Institute

Gerald L. Decker
President & Chief Executive Officer
Decker Energy International, Inc.

Mildred Dresselhaus
Professor
Massachusetts Institute of Tech.

Arthur Hansen
Chancellor
Texas A&M University System

Robert L. Hirsch
Vice President, Exploration &
Production Research
ARCO Gas and Oil Company

Charles J. Hitch
President Emeritus
University of California

John R. Huizenga
Chairman
Department of Chemistry
University of Rochester

John Landis
Senior Vice President
Stone & Webster Engineering Corpotion

Henry R. Linden
President
Gas Research Institute

William T. McCormick, Jr.
President
American Natural Resources Company

Lawrence T. Papay
Senior Vice President
Southern California Edison Company

Ruth Patrick
Limnology Department
Academy of Natural Sciences

David Pimentel
College of Agriculture
Cornell University

Robert H. Pry
Consultant
Center for Innovative Technology

Eric Reichl
President (Retired)
Conoco Coal Development Company

Louis H. Roddis, Jr.
Consulting Engineer

Francis G. Stehli
Dean, College of Geosciences
University of Oklahoma

Victoria J. Tschinkel
Secretary
Department of Environmental
Regulation
State of Florida

STAFF

Joel A. Snow
Acting Executive Director
Energy Research Advisory Board
Department of Energy

MEMBERS OF THE AD HOC REVIEW OF THE NATIONAL RESEARCH COUNCIL REPORT "MAJOR FACILITIES FOR MATERIALS RESEARCH AND RELATED DISCIPLINES"

*Francis G. Stehli, Chairman
Dean, College of Geosciences
University of Oklahoma

Walter Brown
Head of Radiation Research
AT&T Bell Laboratories

Richard Claassen
VP, Livermore Programs
Sandia National Laboratories

*John R. Huizenga
Chairman, Dept. Chemistry
University of Rochester

Edward A. Knapp
Research Advisor
Los Alamos National Laboratory

*Robert H. Pry
President
Center for Innovative Technology

Ralph O. Simmons
Chairman
Department of Physics
University of Illinois

STAFF

Thomas A. Kitchens
Division of Materials Sciences
ER-132
US Department of Energy (GTN)
Washington, DC 20545

Charles E. Cathey
ER-6
Science & Technology Affiars
US Department of Energy
Washington, DC 20585

*ERAB Member

ABSTRACT

The National Research Council-National Academy of Sciences report on "Major Facilities for Materials Research and Related Disciplines" recommends that new facilities and upgrades of existing facilities are very important to the nation. At the request of the Secretary of Energy, the Energy Research Advisory Board has reviewed this report and finds that the Department of Energy is responsible for the majority of these projects to carry out its missions in energy, national defense, and science and technology. Therefore, we recommend that the Department should place a high priority on requesting the new funds necessary to fulfill these responsibilities in the next decade. The energy and defense missions of the Department will be best served by this approach. This responsibility requires strong coordination with other funding agencies through a shared advisory and decision-making process.

The review recommends immediate implementation of new capabilities at existing DOE facilities (the neutron experimental halls at Brookhaven and Los Alamos and the new synchrotron insertion devices at Stanford and Brookhaven) as a cost effective way of maintaining the Nation's leading role in neutron scattering and synchrotron radiation research. It also recommends the immediate initiation of non-site-specific research and development for the proposed 6 GeV synchrotron and advanced steady state neutron source. This pre-construction work should be sufficient to ensure that these facilities will be constructed in a timely fashion at design goals and with well identified costs. Other recommendations concern advancing the Nation's leading capabilities in synchrotron produced ultraviolet radiation and spallation neutron research. A budget scenario is developed.

CONTENTS

I. EXECUTIVE SUMMARY 1

II. BACKGROUND AND CHARGES 7

III. REVIEW PROCEDURES AND CONSIDERATIONS 9

IV. FINDINGS, CONCLUSIONS AND RECOMMENDATIONS 10

V. FUNDING SCHEDULE 20

VI. REFERENCES AND BIBLIOGRAPHY 24

APPENDIX A, EXECUTIVE SUMMARY OF MAJOR MATERIALS FACILITIES REPORT.... A-1

APPENDIX B, SECRETARY'S CHARGE B-1

APPENDIX C, ERAB CHAIRMAN'S CHARGE C-1

APPENDIX D, REVIEW MEETINGS D-1

APPENDIX E, MAJOR BASIC ENERGY SCIENCE FACILITY FUNDING AND USE, FEBRUARY, 1985 .... E-1

APPENDIX F, TELEX FROM THE NATIONAL SCIENCE FOUNDATION F-1

I. EXECUTIVE SUMMARY

Materials are of primary importance in protecting the economic competitiveness of our nation, in efficient and reliable production and use of energy and also in any forseeable new energy and defense technologies. In acknowledgement of this vital role, the Department of Energy and its antecedent organizations, the Energy Research and Development Administration and the Atomic Energy Commission have consistently supported substantial materials research and development programs. The Department currently provides about $350 million annually for materials research and development--making it the largest reported single source of such support in the United States.

Materials research is a broad and diverse group of activities, ranging from concerns with improved mining and minerals processing to fundamental studies of structure and function at the atomic scale. As materials research and development have become more advanced, the associated scientific equipment has become more sophisticated and expensive. Within the last few years, increasing numbers of scientists and engineers involved in materials research and related disciplines have begun to need advanced research facilities such as sources of neutrons, high magnetic field facilities, sources of synchrotron radiation, and special electron microscopes. The Department's laboratories are natural sites for future Major Materials Facilities. Indeed, most of the existing Major Materials Facilities in the U.S. are located at the Department's laboratories and these facilities have commanded an increasing share of the Department's funding for materials research and development.

Due to the diverse capabilities of Major Materials Facilities and the large cost of construction and operations in November 1983, the President's Office of Science and Technology Policy in November 1983 asked the National Research Council to assist in establishing national priorities for future Major Materials Facilities (defined to be those facilities whose initial costs were over $5 million). A committee, co-chaired by D. Eastman and F. Seitz, was formed; it included a balanced representation of scientists and engineers in the materials sciences and the related disciplines. The Major Materials Facilities Committee's report and recommendations were submitted to the Office of Science and Technology Policy in July 1984.

In July 1984 the Secretary of Energy requested that the Energy Research Advisory Board review the National Research Council Committee's report, "Major Facilities for Materials Research and Related Disciplines," and recommend an appropriate Department response in terms of:

- The Department's programmatic interests
- Importance to the nation
- Budget considerations of cost and time
- Urgency of action and overall priorities

This report provides the rationale, analysis and recommendations for the Department's action in response to the Secretary's request.

A. Findings

A forefront capability in materials research is vital to our future economic competitiveness and national security. The Major Materials Facilities report has thoroughly examined the anticipated future national needs and opportunities for major materials research facilities and has done an effective job of establishing scientific priorities. We agree with the general conclusion of the Major Materials Facilities Report; namely that, over the next decade, the nation should develop and construct an array of major new facilities and add new capabilities at some existing facilities. This will strengthen the nation's research base in areas that are of vital importance to the nation's future, including energy and security.

We believe that, as indicated in the Major Materials Facilities Report, these needed new investments should not be made in a way that would sap the vitality of other important elements of the materials research enterprise. In particular, support for smaller projects should not be curtailed as a consequence of increased support for existing and new major facilities and existing facilities should be operated productively. Facilities currently under construction should be completed expediently. The fundamental implications of these findings are:

- Significant new investments will be required to equip U.S. science with the modern facilities needed for forefront materials research in the next and future decades.

- Following the priorities outlined in the Major Materials Facilities Report, an overall investment plan is needed that will provide the basis for mutual agreement between the Congress, the Executive Branch, and the scientific community on the pace and sequence of these investments. This plan must be responsive to new ideas and advancements in the rapidly developing technologies associated with the major materials facilities.

- The Department must play the leading role in the development and implementation of this plan due to the responsibilities and capabilities of both the Department and its laboratories. This increase in responsibility must be accompanied with new funds.

These Findings lead to the following general conclusions relevant to the Department's role:

B. General Conclusions

1. The Department has vital needs for state-of-the-art neutron and photon facilities for materials research and research in related scientific disciplines. These needs reflect the Department's responsibilities for research related to energy and national defense.

ii. The Department already has a central role in providing such facilities primarily through its national laboratories because of their expertise in the design, construction and operation of large accelerator and reactor facilities for national programs. This central role extends beyond the energy mission of the Department to include the nation's broad science and technology base. Scientists from universities, industry, the Department, and other Federal agencies use and depend upon the Department's facilities. However, this broad role can only be adequately carried out with new funds not only for construction but also for the necessary research and development associated with the construction and operating expenses for the new facilities and capabilities generated.

iii. For the evolution and application of new materials knowledge, the Department and the nation depend on the intellectual efforts of a very diverse cadre of scientists and engineers working in laboratories of all types and sizes. It is essential that the Department continue to strongly support the diverse group. Major new tools for materials research are needed but must be developed and made available with new funds.

iv. To ensure the vitality of the diverse area of materials research and its balance with major materials science facilities, it is essential that the Department's management develop a strategy which explicitly includes the necessary pre-construction research and development, construction, and operations of major facilities and research funding to utilize these facilities. The strategy must involve strong coordination with other funding agencies through a shared advisory and decision-making process.

We want to further stress the essential conclusions above. The facilities and upgrades recommended by the Major Materials Facilities Report are important to the nation and to the missions of the Department. The Department--and only the Department--can respond to the majority of the recommendations of the Report. We conclude that the Department, in its broad mission to contribute to the nation's science and technology base, should explicity take the major responsibility of providing major new facilities and capabilities for this vital area. The Department should urgently and aggressively seek the necessary new funds to fill these new responsibilities in the next decade. We believe the energy and defense missions of the Department will be best served by this approach. This responsibility for Major Materials Facilities requires strong coordination with other funding agencies through a shared advisory and decision-making process. The remainder of our discussion is based on this broad responsibility.

We conclude that the prerequisites and scientific priorities set down in the Major Materials Facilities Report are consistent with the needs of the Department and are in the best interest of the Nation. The Report has taken a very hard look at all the needs for major facilities and has carefully assigned priorities to the important needs. Our recommendations for the Department's response related to the specific major facility items in the Report are as listed below. Each recommendation requires immediate and future actions. It is clearly neither feasible nor desirable to fund all of the items in the Major Materials Facilities Report simultaneously. Implementation of the Report requires an investment strategy that meets realistic needs on a reasonable timetable and resolves uncertainties without undue exposure to cost escalation and with attention to possible cost savings.

C. Recommendations

i. The first three items in the Major Materials Facilities Report having to do with new capabilities at existing facilities should be implemented as quickly as possible. The incremental research value gained for the nation from these additions of moderate expense to the neutron facilities at Los Alamos, Brookhaven, and the National Bureau of Standards and of advanced insertion devices to the photon facilities at Brookhaven, Stanford, and Wisconsin will be extremely cost effective.

   o The provision of guide hall facilities and associated instruments for cold neutron research is vital for strengthening neutron beam research in the United States. A start has been made by the President's FY 1986 budget request for such an upgrade at the National Bureau of Standards. The proposed facilities at Brookhaven, which serve research purposes distinct from the upgrade at the Bureau, should be implemented as quickly as possible.

   o Adding new insertion devices to existing synchrotron sources at Stanford, Brookhaven and Wisconsin is of major importance to increased capability for national research at these facilities. The research and design of these additional insertion devices should begin now so that construction can follow the new capabilities at synchrotron radiation facilities already included in the FY 1985 and FY 1986 budgets. It is also vital for gaining experience with undulators, a key element in the next generation of synchrotron radiation sources.

   o An immediate commitment to construction of the experimental hall and key instrumentation at the Los Alamos facility for spallation neutron research is needed. Until this is accomplished, this important facility cannot function as an effective user-oriented activity. When supported by concurrent developments in target and moderator design and in usable instruments matched to this high flux facility, this relatively modest addition should enable the United States to maintain its leadership in this field.

ii. Both the 6 GeV synchrotron and advanced steady state neutron facilities have the potential to provide order-of-magnitude, or greater, improvements in scientific capability. These two projects have the first and second scientific priorities for new construction in the Major Materials Facilities Report. These are large investments and would provide significant facilities which will operate well into the next century. A program of non-site-specific research and development and engineering design should be immediately initiated. Construction commitments should not be made but funding for the pre-construction research and development should be explicitly provided. This should lead to proposals in two to five years for facilities that can be built with confidence for successful and timely operations at design goals and well identified costs.

iii. There is a recognized need for additional photon facilities in the vacuum ultraviolet both for the overall scientific community and for the research needs of the Department's defense programs. The Major Materials Facilities Report assumed that part of the near term need would be met by the Wisconsin Synchrotron Radiation Center's Aladdin ring, presently under construction. The decision on when the Department should proceed with a 1-2 GeV high brightness synchrotron radiation facility, for which designs exist, must take into account the resolution of difficulties that have arisen with Aladdin subsequent to the Major Materials Facilities Report. If the National Science Foundation decides not to complete and operate Aladdin, the 1-2 GeV synchrotron will be more urgently needed.

iv. The work on enriched pulsed neutron target and moderator assemblies already under development at Argonne should be vigorously pursued and plans should be developed and evaluated to integrate such low-cost enhancements into spallation neutron facilities at Argonne and Los Alamos. These efforts should be followed by research and design studies of a future spallation neutron source capable of peak fluxes in the range of 10^{17} neutrons/cm^2-sec. Decisions on construction of future higher intensity neutron facilities should be based on these studies, the work on the new reactor recommended above, and accumulated international experience obtained with the spallation sources presently going into operation and existing steady state sources.

The National Science Foundation has accepted responsibility for upgrading the National Magnet Laboratory. This is important to the Department because of the need for superconductor research and development associated with accelerator and fusion magnets. As previously noted, the Department of Commerce is seeking funding to provide cold neutron capability at the National Bureau of Standards' reactor. These two steps, if successful, are complementary to the Department's actions recommended above and provide important contributions to the overall scientific capability of the nation. They underscore, however, the multiplicity of Federal efforts in materials research and the need for effective coordination in the advisory and decision-making process. As the principal sponsor of research facilities in this area the Department should take the initiative in establishing such a process. The Major Materials Facilities Report also refers to a need for further panels to address important aspects of materials research other than major materials facilities. We support this statement.

A budget scenario is developed. It calls for a gradual increase in the construction budget by about $6-7 million per annum for each of 8 years and an increase in the operating budget, for operations, maintenance, and DOE research, of $7-8 million per annum for each of the first 3 years.

II. BACKGROUND AND CHARGES

Materials are of primary importance in protecting the economic competitiveness of our nation, in efficient and reliable production and use of energy and also in any forseeable new energy and defense technologies. In acknowledgement of this vital role, the Department of Energy and its antecedent organizations, the Energy Research and Development Administration (ERDA) and the Atomic Energy Commission (AEC), have consistently supported substantial materials research and development programs. The Department currently provides about $350 million annually for materials research and development--making it the largest reported single source of such support in the United States. Materials sciences and the associated development efforts are a major area of focus for the Department because the limitations of materials properties constrain extant energy production and conversion systems as well as the development of new alternative energy technologies and defense systems. Because of the vital importance of materials to the nation's long-range economic development, security, energy usage and energy conservation, the Department provides approximately one-third of the funding for research and development in the materials sciences.

Materials research is a broad and diverse group of activities, ranging from concerns with improved alloys and welding processes to fundamental studies of structure and properties of materials on the atomic scale. As materials research and development have become more advanced, the associated scientific equipment has become more sophisticated and expensive. Within the last few years, increasing numbers of scientists and engineers involved in materials research and related disciplines have begun to need advanced research facilities such as sources of high intensity neutron beams, high magnetic field facilities, very intense sources of synchrotron radiation, and special electron microscopes. The DOE laboratories are natural sites for Major Materials Facilities. Indeed, the majority of the existing Major Materials Facilities in the U.S. are located at DOE laboratories: these extant facilities and facilities under construction command an increasing share of the DOE funding for materials research and development.

Recently new major materials facilities as well as several upgrades of existing facilities have been proposed. Operational costs, development schedules and construction periods have increased with the sophistication of these new facilities. To expect all of the proposed construction to be initiated over the next few years is unreasonable. Due to the diverse capabilities of Major Materials Facilities and the increasingly larger costs of construction and operations. the President's Office of Science and Technology Policy (OSTP) in November 1983 asked the National Research Council (NRC) to assist in establishing national priorities for future Major Materials Facilities ((MMF)--defined to be those facilities whose initial costs were over $5 million).

A committee of 22 members was formed within the NRC Commission on Physical Sciences, Mathematics, and Resources, representing the diverse disciplines that use facilities for major materials. The Committee's membership was also intended to mirror the differing research styles and the wide spectrum of organizations where the research is done. Scientific work with materials varies from that principally requiring laboratory-scale instrumentation to that dependent on the availability of major facilities. The research is done by governmental, academic, and industrial scientists and engineers.

The Major Materials Facilities Committee, co-chaired by Dean Eastman and Frederick Seitz, first met late in January 1984 and three times thereafter. The task of studying the diverse MMF proposals was difficult. However, the status of neutron scattering and of synchrotron radiation sources had been reviewed recently by panels of experts for the NRC. A 1979 NRC study on High-Magnetic-Field Research and Facilities and a 1984 DOE planning study for advanced synchrotron radiation facilities were also available. The Report of the MMF Committee and its recommendations were forwarded to Dr. Keyworth late in July 1984 and published by the NRC as "Major Facilities for Materials Research and Related Disciplines" (Ref. 1). Appendix A contains the Executive Summary of this report.

In July 1984, the Secretary of Energy requested that the Energy Research Advisory Board (ERAB) undertake ad hoc Reviews of four NRC reports including the one described above (See Appendix B). He recognized that the recommendations and information in the reports could have a major effect on the Department's science efforts in programs of the Office of Energy Research and also on those of other components of the Department. He requested that the Reviews:

- o Examine the substantive recommendations of the reports
- o Assess the significance in terms of the Department's programs and responsibilities
- o Recommend appropriate action and
- o Complete the assessment in six months

Subsequently, Ralph Gens, Chairman of ERAB, asked Arthur Hansen to form a group to review the MMF report (See Appendix C). He requested that the Review:

- o Consider the appropriateness and urgency of DOE implementation of the recommendations
- o Set priorities by considering, from the DOE point-of-view, the needs of present and potential users and the overall importance to the nation
- o Account for timing, costs and urgency of the various choices in a plan for implementing the Reviews recommendations
- o Consider any further needs or requirements which were not fully addressed by the MMF Committee
- o Obtain the views of DOE program personnel and of others having interest in such facilities including potential university, industry and national laboratory project personnel and facility users

A Review consisting of four ERAB members and four external members was assembled. A list of the members follows the transmittal letters. The Review began its deliberations with its first meeting, October 30, 1984.

III. REVIEW PROCEDURES AND CONSIDERATIONS

The external members of the *ad hoc* Review were selected to provide broad expertise in the materials sciences and related disciplines but also to represent national laboratories, industrial and academic institutions as well as many regions of the USA. The Review held three publically announced and geographically distributed meetings: the first was held in Washington, D.C. on October 30, 1984, the second in Berkeley, CA, on December 12, 1984, and the last in Chicago, Illinois, on January 25-26, 1985. This provided the opportunity for participation by the public across the nation. Appendix D. contains the agenda of these meetings. An informal final meeting was held in Washington on April 30, 1985, for the purpose of clearing up some remaining questions and finishing the draft report to be presented to the Energy Research Advisory Board on May 2, 1985.

NRC panels and surveys, DOE topical workshops and planning studies and other sources have produced more than a dozen reports which concern the MMF in the last few years. Consequently, much of the information pertinent to the Review was read by the members. See Section VI for the bibliography of reports used in this review. The first meeting was devoted to determining the response other Federal agencies expected to make to the MMF Report. Briefings on the applications of neutron research and synchrotron radiation research were given in the first and the second meetings. Speakers on neutron research and synchrotron radiation research were carefully chosen to be experts but with minimal institutional stock in the MMF Report recommendations. Before the second meeting, all of the DOE Laboratories were polled for their thoughts on the MMF Report recommendations in regard to their mission, their use of the MMF, and on the statistics of operation and use of any MMF located at their laboratory. (These statistics are presented in summary form in Appendix E.) The second, third, and the informal final meetings contained briefings from the DOE laboratories on these questions and their plans involving new MMF.

IV. FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

The Review, while responding to the charges outlined in II., organized its thoughts around some managerial issues and the recommendations of the MMF Report. Its findings and recommended DOE actions are presented below. From the outset we will assume a familiarity with the MMF Report and the information in its references. For easy reference, Appendix A contains the executive summary of the Report. We suggest a careful reading of the first and second major sections, MATERIALS RESEARCH: FACILITIES AND MODES and MAJOR MATERIALS FACILITIES; SCIENCE AND TECHNOLOGY, respectively. They form an excellent and succinct background for the following discussion. Here we will provide only information on developments since the writing of the MMF Report and give supplementary information important to the concerns of the Department. We believe our conclusions and recommendations are appropriate for the Department in response to its mission and the nation's needs.

From briefings and other information available to us, we find that a forefront capability in materials research is vital for our energy production and usage, our national defense programs, and for a successful economic future which must necessarily be based on 'high technologies'. By the end of our fact-finding meetings, we unanimously agreed on our major conclusion--the prerequisites and scientific priorities set in the MMF Report are generally consistent with the needs of the DOE missions and in the best interest of the nation. The MMF Report is a well-balanced assessment of the national needs and carefully draws its scientific priorities commensurate with these needs. Our next charge was to examine the urgency and sequence of DOE actions and cost scenarios.

We will present our views on the necessary costs to construct the array of major new facilities and new capabilities at existing facilities which have been recommended by the MMF Report and this Review in Section V. We find that a significant investment of additional resources will be required to provide the nation's scientists and engineers with the recommended modern facilities for forefront materials research in the next years and into the future decade. A conservative balanced overall plan based on the priorities of the MMF Report is required to secure the mutual agreement and support of Congress, the Executive Branch and the scientific community on the sequence and rate of expenditures. This plan must be responsive to new information and technological innovations as they become available.

The Department is presently responsible for the maintenance and operation of most of the major research facilities in the physical sciences (Ref. 2). This statement also holds for the MMF subset (Ref. 3 and 4). The excellent capabilities of both the Department and the DOE laboratories to administer, develop, and construct major research facilities strongly support the conclusion that the DOE must play a leading role in implementing the overall MMF plan.

During the review, a few observations were made that have apparently not been widely recognized. The first is that the MMF are not of the same character as other 'Big Science' facilities. The general mode of utilization is that a user initiates a research program in a home laboratory and uses the MMF when special capabilities unavailable in the home laboratory are needed. In this sense the MMF are not 'large-scale science' but instead play host to many small-scale projects. For example, the National Synchrotron Light Source will support nearly 100 simultaneous experiments when it is fully operational. It is interesting that its operating budget is actually much less than that required to operate enough rotating anode X-ray sources to produce the same integrated flux of X-rays, yet its capabilities are far greater due to the special characteristics of its X-ray emissions, such as the polarization and the very small divergence. It is, however, important to recognize the vital role of the home laboratory, where much of materials science is developed and young scientists are being trained. We find that it is essential to maintain the diversity of the home laboratories as the wellspring of research on materials and, just as importantly, the source of young scientists.

It was also noted that support of operations of the extant MMF from the DOE Division of Materials Sciences (DMS) is increasing but leveling off near one-fifth of its budget--a point of concern in reference 5 and, indirectly, in the MMF Report. However, the MMF operations portion of the total national budget for materials research and development and the related disciplines is not more than 5 percent. [We arrive at this number by noting that the DMS budget is only about one-third of the total materials research and development budget in the Department and that the Department's budget is only about one-third of the total national budget for materials research and development. Accounting for the utilization of the MMF by the related disciplines and the MMF supported by other agencies, the portion remains less than 5 percent.] Even large increases, say by 40 percent in the operations costs of the MMF could be balanced in the sense of the first prerequisite of the MMF Report by an additional coordinated 2 percent [40 percent of 5 percent] increase in the total national materials research budget. It is important that this small but not insignificant increase be assured by a strong coordination between the Department, other funding agencies, and Congress.

However, the increasing portion of the DOE Division of Materials Sciences budget for MMF is of special concern to the DOE (Ref. 5) and to those supported by that Division. Our poll of the DOE laboratories indicates that those laboratories that host a MMF have suffered reductions in the components of their materials research budgets not specifically associated with the MMFs. This has resulted in a shift of the mission of several laboratories from materials-related research to facility operation. This reduction in DOE materials research is detrimental to the mission of the Department. To maintain the vitality of the DOE materials effort, a budget strategy must be developed which removes this adverse effect. However, we do not advocate the most obvious solution, that MMF construction and support become an independent item in the DOE budget because of the concomitant decrease in flexibility to meet unanticipated needs.

We also studied the channels of coordination and advice to the DOE Division of Materials Sciences. At the top level, coordination with other federal agencies involved in materials research and development is provided by the Committee on Materials, (COMAT) presently chaired by Dr. J. McTague of OSTP. Strong interagency coordination at the program level for materials science is done through the Interagency Materials Group, a sub-group of COMAT, other interagency committees on special topics, and direct personal contact. Coordination within the Department is accomplished primarily through the Energy Materials Coordinating Committee. The Division of Materials Sciences has a Council on Materials Sciences which provides information on technical emphasis through *ad hoc* panel meetings and assists the Division in establishing research priorities and user facilities policy. The majority of information about facilities is obtained by the Division through *ad hoc* expert groups and National Research Council/National Academy of Sciences committees and studies. An example of the latter is the MMF study itself. There are two standing NRC/NAS groups which provide important information to the Division; the National Materials Advisory Board and the Solid State Sciences Committee. The latter of these has organized several studies on specific needs for MMF, a few of which are listed in the references. This plethora of coordination and advisory mechanisms illustrates the lack of organizational cohesiveness for the Federal Government's effort in the full field of materials research. Workers in materials science are represented by several professional societies. There is no one body which can speak for even a majority of interests of the materials and materials-related scientists and engineers. We believe the DOE must continue to maintain strong inter- and intradepartment coordination and foster the development of a shared advisory and decision-making process. The process must be developed to at least adequately represent the more basic side of materials research namely, materials science, in the United States: it must be capable of reaching consensus on priorities within the concerned scientific community, the federal agencies, and Congress. The recent move toward joint endeavors by the two groups in the NRC/NAS is laudatory--perhaps the first step toward the goal we have set here.

We found in our meeting with representatives from other federal agencies responsible for funding of materials sciences and the related disciplines which utilize the MMF that they have limited interest in constructing future MMF. It should, however, be noted that the Department of Commerce enthusiastically supports its reactor and the planned upgrade. The Department of Commerce also supports its Synchrotron Ultraviolet Radiation Facility (SURF-II) which was not the object of a recommendation of the MMF Report.

The National Science Foundation (NSF) is responsible for the Wisconsin Synchrotron Radiation Center (SRC) with its two rings, the older 240 MeV Tantulus and the 800 MeV Aladdin, which is in a commissioning stage. The NSF is responsible for the Nation's only very high magnetic field facility, the Francis Bitter National Magnet Laboratory at the Massachusetts Institute of Technology, and expects to respond to the MMF recommendations concerning this MMF. The NSF also expressed an interest in the initial site-independent exploratory design and development associated with the 6 GeV synchrotron source(see Appendix F). The NSF also supports the Cornell High Energy Synchrotron Source (CHESS), a facility parasitic on the 5.5 GeV Cornell Electron Storage Ring (CESR) facility which was not the object of a recommendation in the MMF report.

There are formal and informal cooperative programs at the DOE MMF with other countries. The only formal programs are arrangements with the Japanese Atomic Energy Research Institute and the University of Tokyo's Institute of Solid State Physics with Brookhaven and Oak Ridge National Laboratories. Two state-of-the-art neutron spectrometers are being built with Japanese funds in exchange for the use of these and other spectrometers on the High Flux Beam Reactor (BNL) and the High Flux Isotope Reactor (ORNL). Appendix E contains a tabulation illustrating the utilization of these and other DOE user facilities by foreign scientists. The majority of these utilizations are informal and almost always involve long-term basic science in collaboration with American workers. Though we encourage specific international cooperative research and instrument/technique development efforts of the type described above, we do not believe MMF construction or upgrades should be accomplished by international cooperation. The recommendations in this report refer to MMF important to U. S. industry and, if present DOE policy is followed, are available on a full reimbursement basis for industrial proprietary work. This commercial utilization is increasing and we believe it will continue to increase. Accessibility to state-of-the-art MMF by American industrial concerns improves the nation's international marketplace competitiveness. We believe that international cooperative facilities would inhibit access to U.S. industrial workers and especially for proprietary use if the facilities are not located in North America.

From our poll of the DOE laboratories, we found that they generally strongly supported the MMF Report recommendations in terms of the DOE missions and of each laboratory's own missions.

From these findings we have reached the following general conclusions and recommendations.

A. General Conclusions:

i. The DOE has vital needs for state-of-the-art neutron and photon facilities for materials research and research in related scientific disciplines. These needs reflect DOE mission responsibilities for research related to energy and to national defense.

ii. The DOE already has a central role in providing such facilities, primarily through its national laboratories due to their expertise in the design, construction, and operation of large accelerator and reactor facilities for national programs. This central role extends beyond the energy mission of DOE to include the nation's broad science and technology base. Scientists and engineers from universities, industry, the DOE, and other Federal agencies use and depend upon the DOE facilities. However, this extended role can only be adequately carried out with new funds not only for construction but also for the necessary research and development associated with the construction and operating expenses for the new facilities and capabilities generated.

iii. For the evolution and application of new materials knowledge the DOE and the nation depend on the intellectual efforts of a very diverse cadre of scientists and engineers working in laboratories of all types and sizes. It is essential that adequate support of that group in its diversity must remain strong. Major new tools for materials research are needed but must be developed and made available from new funds.

iv. To ensure the vitality of the diverse area of materials research and its balance with major materials science facilities, it is essential that DOE management develop a research strategy which explicitly includes the necessary pre-construction research and development, construction, and operations of major facilities as well as funding for instrumentation and research on the facilities. This strategy must include strong coordination with other funding agencies through a shared advisory and decision-making process.

We want to further stress the essential conclusions by recapitulation. The facilities and upgrades recommended by the Major Materials Facilities Report are important to the nation and to the missions of the Department. The Department--and only the Department--can respond to the majority of the recommendations of the Report. We conclude that the Department, in its broad mission to contribute to the nation's science and technology base, should explicity take the major responsibility of providing major new facilities and capabilities for this vital area. The Department should urgently and aggressively seek the necessary new funds to fill these new responsibilities in the next decade. We believe the energy and defense missions of the Department will be best served by this approach. This responsibility for Major Materials Facilities requires strong coordination with other funding agencies through a shared advisory and decision-making process. The remainder of our discussion is based on this broad responsibility.

The MMF Report details two categories of recommended scientific priorities: major new facilities and upgrades of existing facilities. The Report points out that they complement one another in function, time and required resources. The upgrades are essential to provide the Nation's research needs during the next decade. Planning and designing of new facilities must start now because of the lead time, five to ten or more years, required to construct major new synchrotron radiation and neutron sources. The Report provides a scientific priority list for each category, but not a sequential order of implementation. As we understand from presentations by the authors of the Report, if an item lower on the priority list is undertaken, it should not jeopardize the undertaking of one above it.

We find the prerequisites and scientific priorities set in the MMF Report consistent with the needs of the Nation and with the needs of the DOE. Below, we recommend a sequence of DOE actions consistent with the scientific priorities of the MMF report, the DOE missions and also events since the writing of the MMF report. Each of our recommendations specifies immediate actions and provides a sequence of actions over the next several years. It is important to note that this report, written less than a year after the MMF report, is being assembled in a time of intense budgetary constraint. It is clearly neither feasible nor technically desirable to fund simultaneously all of the construction discussed in the MMF Report.

B. Recommendations

1. The first three items in the MMF Report having to do with upgrades of existing facilities should be implemented as quickly as possible. The incremental research value gained from these modest additions to the neutron facilities at LANL, BNL, and NBS and of the advanced insertion devices to the photon facilities at BNL, Stanford, and Wisconsin will be extremely cost effective.

   o The provision of guide hall facilities and associated instruments for cold neutron research is vital for the continued health of neutron beam research in the United States.

   Funding for the NBS hall is in the President's FY 1986 budget. If this hall were constructed this need would be partially met. However, we realize that the proposed upgrade of the High Flux Beam Reactor (HFBR) at BNL has a different complement of neutron scattering spectrometers and, in addition to its use for materials research and biological studies using neutrons, the upgrade will satisfy the needs of positron annihilation studies of materials and some in nuclear physics. Further reasons for the priority of this upgrade are given in the MMF Report.

   o Adding insertion devices to the existing synchrotron sources is of major importance if we are to increase our capability for national research at these facilities. The research and design of these additional insertion devices should begin now so that construction can follow the new capabilities at synchrotron radiation facilities already included in the FY 1985 and FY 1986 budgets. It is also vital for gaining experience with undulators, a key element in the next generation of synchrotron radiation sources.

   Arguments for this item are documented in the MMF Report, reference 7 and reference 8.

   o An immediate commitment to construction of the experimental hall and key instrumentation at the Los Alamos facility for spallation neutron research is needed. When supported by concurrent developments in target and moderator design and in usable instruments matched to this high flux facility, this relatively modest expenditure should enable the United States to maintain its leadership in this field.

The Intense Pulsed Neutron Source (IPNS) at ANL is now very heavily oversubscribed. The Los Alamos hall is an integral part of a DOE plan to maintain the nation's lead in spallation sources, a plan based on the research opportunities using pulsed neutrons and epithermal neutrons. This plan called for initiation of construction of the hall at Los Alamos in FY 1984. Its construction had been approved by the DOE. The Proton Storage Ring (PSR), built with funds from the DOE defense programs, will make the facility one of the most intense pulsed sources of neutrons in the world. The PSR is in the final commissioning stage: it should operate within the year. As a result of the workshop on neutron scattering held on Shelter Island, October 1984, (Ref. 6) the potential of spallation neutron sources is now better appreciated. The immediate international competition is manifested in the Spallation Neutron Source in England which has capabilities comparable with those potentially available at Los Alamos. It is also in a commissioning stage. We are losing our clear lead position but could remain competitive with the Los Alamos upgrade if appropriations were made in FY 1987. We emphasize that this competitive stance can be lost unless pulsed neutron techniques are pursued aggressively without interruption of the evolving programs of the user community. It is important for instrument development needs to be appropriately phased over a period of time, and workable criteria and schedules be established for any transfer from ANL to LANL so that the relevant user community is afforded continuous research opportunities.

ii. Both the 6 GeV synchrotron and advanced steady state neutron facilities have the potential to provide order-of-magnitude or more improvements in scientific capability. These are large investments and would provide significant facilities which will operate well into the next century. A program of non-site-specific research and development and engineering design should be immediately initiated. In these two cases there are uncertainties of cost and design that must be resolved. Construction commitments should not be made at this time but funding for the pre-construction research and development should be explicitly provided. This should lead to proposals in two to five years for facilities that can be built with confidence for successful and timely operations at design goals and well identified costs.

These projects have the first (6 GeV Synchrotron) and second (advanced steady state reactor) scientific priorities for new construction in the MMF Report. The report provides justification for these scientific priorities. The DOE is the only federal agency able to adequately address the task of building these facilities. Such large scale forefront facilities should avoid commissioning and other difficulties if they are well planned. Adequate designs do not now exist. If the DOE is to be in a position to make a knowledgeable decision on how and when to construct these facilities with completion dates within this century, the pre-construction research and development must begin now. The research and development effort is required to determine costs and define operating capabilities before sites can be selected and construction begun. There are many steps in this sequence that can lead to delays unless DOE proceeds expeditiously. These tasks are too large and important to depend upon the DOE laboratories to absorb the costs of the pre-construction research and development--although substantial design efforts are now underway at several laboratories. Decisions for early construction of lower priority facilities must not interfere with the design and construction of these two top priority facilities.

Workshops on the capabilities needed for the 6 GeV synchrotron have begun. The first was held in Ames, Iowa, in October 1984 (Ref. 9) and a second in Gaithersburg, Maryland, in March 1985. The interested community of scientists is moving rapidly toward defining the desirable characteristics of this machine and interacting with accelerator designers to determine what is feasible. Future workshops are planned in 1985 and 1986 to consider other related subjects such as the insertion devices and beam line instrumentation for this advanced facility.

For over a year, ORNL has had a planning and design effort (about six man-years) on an advanced steady-state neutron source using internal laboratory funds (Ref. 10). Several case designs have been evaluated, a research and development program has been planned, a preliminary cost estimate has been made, and computer programs have been written for evaluating different reactor designs from the thermal hydraulics and structural mechanics viewpoints. Cost/benefit studies have demonstrated the wisdom of building a new facility rather than modify the existing High-Flux Isotope Reactor. A workshop on instrumentation for this new reactor has been held (Ref. 11) and a workshop on reactor design is being planned.

Again we remind the reader that the major reasons for the high priority each of these two major facilities commands are given in the MMF Report. Recent developments only strengthen these priorities. The picture is sufficiently clear: only a few words are necessary here.

iii. There is a recognized need for additional photon facilities in the Vacuum UltraViolet (VUV) both for the overall scientific community and for research needs of DOE weapons programs. The MMF Report assumed that part of the near-term need would be met by the

Wisconsin Synchrotron Radiation Center's Aladdin ring, presently under construction. The decision on when DOE should proceed with a 1-2 GeV high brightness synchrotron radiation facility, for which designs exist, must take into account the resolution of difficulties that have arisen with Aladdin subsequent to the MMF Report. If the National Science Foundation decides not to complete and operate Aladdin, the 1-2 GeV synchrotron will be more urgently needed.

In our briefings on synchrotron radiation and by representatives from the laboratories, we found that the scientific argument for the 1-2 GeV and the 6 GeV synchrotron radiation sources were both strong and that both are needed. The 6 GeV ring was given higher scientific priority because it would lead the world in its capabilities and in addition provide VUV radiation while the converse is not true. On the other hand, the VUV ring at the NSLS (BNL) is saturated--at least two 'refugees' from the Aladdin ring have already been accommodated. LLNL and LANL have future needs for a VUV source available for unclassified defense research and possibly classified research (a restricted access area may be required) in the future. Though some defense research can be done on the NSLS VUV ring, the present fully committed condition makes it awkward to expand the effort. The demonstrated need and the availability of a good preliminary design (with parameters established by a workshop involving the user community (Ref. 12)) should advance the position of a 1-2 GeV source in the DOE action sequence if the Aladdin project were to be cancelled. Some preconstruction research and development, probably a year in duration and a cost of $2-3 million, would be necessary to improve the existing design.

If the NSF does decide to complete the Aladdin ring, it is important to recognize that Aladdin is not a substitute for the 1-2 GeV ring. The latter would provide much higher brightness and be optimized for the use of insertion devices. A design has been reviewed by the DOE for this ring.

iv. The work on enriched pulsed neutron targets, and cold and 300K moderator assemblies, already under development at Argonne, should be vigorously pursued and plans should be developed and evaluated to integrate such low-cost enhancements into spallation neutron facilities at Argonne and Los Alamos. These efforts should be followed by research and design studies of future spallation neutron sources capable of peak fluxes in the range of 10^{17} neutrons/cm^2-sec. Decisions on construction of future higher intensity neutron facilities should be based on these studies, the work on the new steady-state reactor recommended above, and accumulated international experience obtained with the spallation sources presently going into operation and existing steady state sources.

> The MMF Report overestimates the cost of the enriched target assemblies. It is important to recognize the new capabilities that spallation sources will have when they are outfitted with enriched targets and new efficient epithermal, ambient and cryogenic moderators. ANL has a new cryogenic moderator in operation which forms a source of intense neutrons as cold as any steady state source. This advance removes the common perception that spallation sources can not produce cold neutrons. Continuing to pursue this approach could lead to an alternate means of achieving a new and advanced cold neutron capability in the same facility with the intense pulsed epithermal and thermal neutron beams for which spallation sources are known.
>
> Though we concur with the MMF Report that future action on construction of a spallation neutron source should depend upon accumulated experience, we believe that this experience will accumulate rapidly due to the strong user program at the ANL IPNS, the British Spallation Neutron Source, which is now being commissioned, and the LANL spallation neutron source as it reaches full capability. from the actions recommended above. At the present time the United States has a slight lead in this field. We can remain competitive through careful nourishment and management including the action recommended above, an a strong and continuous instrument development program, and support for the growing user community. At the same time, advantage should be taken, to the extent possible, of the new vigorous European programs in pulsed sources. Pulsed neutron source technology and experience is quickly growing and we are concerned about losing our competitive position. In order that a proper decision can be made in about five years, some research and design must continue on spallation sources to accumulate the necessary expertise for timely exploitation of these new techniques. Our knowledge of the two types of neutron sources should form a sound basis for a coherent plan, to be determined by either the shared advisory and decision process recommended above, or an independent multidisciplinary advisory group convened for that purpose, to meet the long-term neutron beam research needs of the scientific community. This recommendation is consistent with those by the NRC/NAS 1984 Panel on Neutron Scattering (Ref. 13).

The NSF has accepted responsibility for upgrading the National Magnet Laboratory. This is important to DOE because of the need for superconductor research and development associated with accelerator and fusion magnets. As previously noted, the Department of Commerce is seeking funding to provide cold neutron capability at the NBS reactor. These two steps, if successful, are complementary to the DOE actions recommended above and provide important contributions to the overall scientiic capability of the nation. They underscore, however, the multiplicity of Federal efforts in materials research and the need for effective coordination in the advisory and decision process. As the principal sponsor of research facilities in this area, the DOE should take the initiative in establishing such a process. The Major Materials Facilities Report also refers to a need for further panels to address important aspects of materials research other than major materials fcilities: we support this statement.

V. FUNDING SCHEDULE

A significant investment of additional resources will be required to provide the nation's scientists and engineers with the recommended modern facilities for forefront materials research in the next few years and into the future decade. A conservative balanced overall plan based on the priorities of the MMF Report is required to secure the mutual agreement and support of Congress, the Executive Branch and the full scientific community involved in the sequence and rate of expenditures.

In order to understand the possible funding schedules associated with our recommendations, we have spoken with the Basic Energy Sciences personnel, studied the DOE Division of Materials Sciences long-range plan (Ref. 14), the MMF Report and information from subsequent workshops (Refs. 6, 10, and 12). Below are some general remarks and an approximate funding schedule. Detailed planning is beyond the capability of this Review and must be done by the Department.

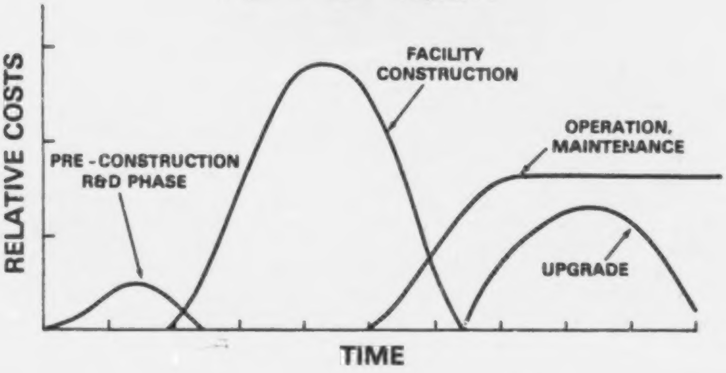
An important facet of MMF planning is accounting for the substantial costs associated with a new facility other than the actual construction costs. Before construction of a facility begins, a program of non-site-specific research and development is necessary. It must be adequate to insure that the facility can be built with confidence for successful and timely operation at design goals and well identified costs. In the past, this pre-construction R&D has not been sufficient to accomplish these goals. As the sophistication and complexity of the MMF increases, it is much more important to reach these goals. The total estimated cost of this work is about 10 percent of the total construction costs. The importance and costs of this work are too great to expect the prospective landlords of a major facility to absorb them. The R&D must be explicity budgeted by the Department.

It is equally important to understand that the operation and maintenance costs of a new major facility are large and ongoing. These costs compete for the same budget monies as other research funding, a point addressed in our discussion on the MMF prerequisites above. If a major facility is to be built, operation and maintenance costs sufficient for effective utilization must be an integral component of the planning. Some of these new operating and maintenance expenses must be compensated by reducing expenses at other facilities and by shutting down some older facilities. New facilities, providing better and usually new capabilities, are often more expensive to operate and maintain; full compensation can not be expected. Similarly, expenses of research utilizing the new sophisticated facilities will increase over those associated with the older facilities. The MMF Report estimates that these costs are about 10-15 percent of the total construction cost per annum for synchrotron facilities and about 4-6 percent of the total construction cost per annum for neutron facilities. We suspect that these estimates are too low but do not have better estimates.

Due to the rapidly developing technologies associated with these major facilities and the long pre-construction and construction phases, it is likely that there will be upgrades to newly constructed major facilities. This element can not be planned but should be anticipated. It is not valid to assume that more pre-construction research and development or simple waiting will alleviate this possible encumberance; often the technological advance and new scientific opportunities are established during early operation and instrument development. Delaying construction only insures a reduced national capability to meet our economic and technological competition. The four cost elements are presented in the schematic funding profile for a major facility in Figure 1. The elements are optimistically scheduled in this figure. Proper detailed planning by the DOE should optimize the phasing of the elements for each new facility.

Figure 1

SCHEMATIC FUNDING REQUIREMENTS FOR A NEW FACILITY



We have recommended immediate funding of three new capabilities at existing facilities. The Department's capability to act on these recommendations depends on its existing commitments (and the process of consensus building by the interested user community in the larger scientific community, the DOE, the Executive Branch and in Congress). Shown in Figure 2 are the existing commitments at the time of the DOE Division of Materials Sciences long-range plan (Ref.14). We conclude that the advanced insertion devices should start in the second year to smooth the financial loads and to allow NSLS Phase II and the improvement underway at Stanford to be completed.

Figure 2
APPROVED CONSTRUCTION
(ACTUAL YEAR DOLLARS)

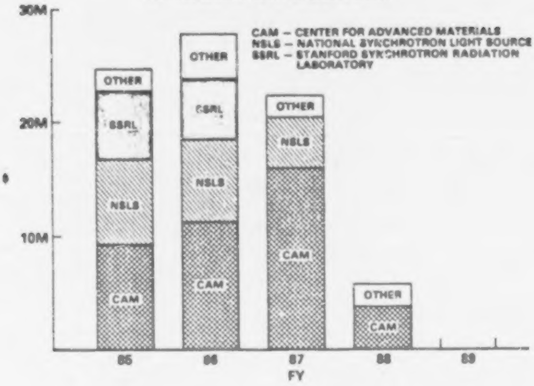


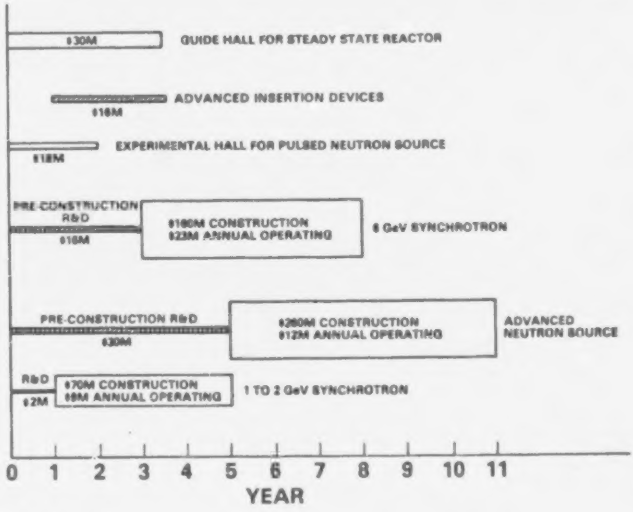
Figure 3 is an adaptation of the long-range plan developed by the DOE Division of Materials Sciences (Ref. 14). Several comments are in order. Estimated construction and operating costs are those given in the MMF Report: we believe that they are underestimated. The boxes do not imply uniform yearly funding but only the total estimated cost and the approximate duration of each phase. We have not included in the figure the addition of new advanced insertion devices at Wisconsin and have estimated about $16M for such devices at the NSLS (BNL) and SSRL (Stanford). We estimate that the $30 million pre-construction research and development for advanced neutron sources should begin at the $2.5 million level with about 80 percent going to studies on steady-state sources. Construction projects for the two neutron halls and the 1-2 GeV synchrotron have been previously recommended and have DOE approved construction plans. Pre-construction research and development and the advanced insertion devices costs should be supported by operating and equipment funds as well as by construction funds.

In conclusion, we find that substantial increases in construction commitments must be made, but a reasonable financial plan for the next decade to accommodate the recommendations is possible. For example, if a plan based on the schedule laid out in Figure 3, is implemented starting in FY 1987, then (1.) an annual real increase (in FY 1985 dollars) of about $6-7 million in the DOE Division of Materials Sciences construction budget for each of the first 8 years (over the level in FY 1986), and (2.) an annual real growth (in FY 1985 dollars) of about 6-7 percent, $7-8 million, in the Division's operating budget for each of the first 3 years will provide for the additional expenses associated with the new capabilities at existing facilities and with new facilities. This scenario assumes the 1-2 GeV synchrotron source is delayed one year to improve the design with $2-3 million of pre-construction research and development expenses. Operating and maintenance costs of the three recommended new capabilities are about $4-5 M per annum. Costs that will arise more than 3 to 5 years in the future are imperfectly known--we believe the MMF estimates, which are used here, are 10-20% too low. Future workshops and pre-construction research and development will be necessary to determine these expenses. A second possible plan which allows an early start to all of the recommended construction is provided in the MMF Report.

We have pointed out above that not all of the facilities needs are within materials sciences. It follows that not all of the new research and instrumentation funding associated with this plan should derive from the DOE Division of Materials Sciences, but the Division's core research budget will need real annual increases of 2-3 percent over the decade to support its share. This provides for the expanded support as well as some of the additional support of smaller scale research programs and instrumentation mandated by the prerequisites in the MMF Report.

Figure 3

MAJOR MATERIALS FACILITIES PROJECTS
(AREAS PROPORTIONAL TO COSTS IN FY 1985 DOLLARS)



VI. REFERENCES AND BIBLIOGRAPHY

1. Major Facilities for Materials Research and Related Disciplines, NRC Major Materials Facilities Committee, D. E. Eastman and Frederick Seitz, Co-Chairmen, National Academy of Sciences, August, 1984.

2. User's Guide to DOE Facilities, DOE/ER-0174, January, 1984.

3. Office of Basic Energy Sciences 1984 Summary Report, DOE/ER-0146/1, November, 1984

4. Materials Sciences Programs - Fiscal Year 1984, DOE/ER-143/2, September 1984.

5. Materials Research and Development, ERAB Materials R&D Panel, Robert H. Pry, Chairman, DOE/S-0027, November 1983.

6. "Scientific Opportunities with Advanced Facilities for Neutron Scattering", G.H. Lander and V.J. Emery, editors, Shelter Island, NY, October 1984.

7. Current Status of Facilities Dedicated to the Production of Synchrotron Radiation, NRC Solid State Sciences Committee, Subcommittee on Synchrotron Radiation Facilities, D.W. Lynch, Chairman, National Academy of Sciences, Washington, D.C., 1983.

8. Planning Study for Advanced National Synchrotron--Radiation Facilities, National Synchrotron-Radiation Planning Committee, M. Knotek and P. Eisenberger, Co-Chairman, Sandia National Laboratories, Albuquerque, NM, 14 March 1984.

9. Synchrotron Radiation Source Research and Development - Report of a Program Review, D. Lynch and M. Weber, presiders, Ames Laboratory, October 1984.

10. ORNL Presentation to the Major Materials Facilities Committee or the National Research Council, ORNL, D.C. Bartine et al., February, 1984, and The Center for Neutron Research, Prepared by Oak Ridge National Laboratory, March, 1985.

11. "Proceedings of the Workshop on Instrumentation for the Advanced High-Flux Reactor", R. Moon, editor, Oak Ridge National Laboratory, CONF-8405192, May, 1984.

12. Report on ALS/SSRL User Workshop, A. I. Bienenstock, T. Elioff and G. E. Haller, Co-chairman Lawrence Berkeley Laboratory, Pub. 5095, May 1983. See also National Center for Advanced Materials, Scientific Program Summary, Pub. 5087, Lawrence Berkeley Laboratory, April 1983.

13. Current Status of Neutron-Scattering Research and Facilities in the United States, NRC Solid State Sciences Committee, Panel on Neutron Scattering, John J. Rush, Chairman, National Academy of Sciences, Washington, DC 1984.

14. Materials Sciences Division - Long Range Plan, DOE/ER-0212, December 1984.

15. Articles on Neutron Scattering in Physics Today 38, No.1, January 1985.

16. "Large facilities for condensed-matter science", M. Blume and D. Moncton, Physics Today 38, No.3, March, 1985.

APPENDIX A

Materials Facilities for Materials Research and Related Disciplines

NRC Major Materials Facilities Committee
D. E. Eastman and Frederick Seitz, Co-Chairman
National Academy of Sciences, 1984

EXECUTIVE SUMMARY

The science of condensed matter, or materials research, deals with the properties of solids and liquids and their interfaces. It is interdisciplinary, involving materials science, major areas of physics and chemistry, and the earth sciences, biology, and medicine. The understanding of the behavior and properties of materials undergirds every major technology; as a consequence, strength in materials research is essential to national capacities in advanced technology and, hence, to economic competitiveness.

Like all sciences, materials research depends on instruments, with these instruments ranging from laboratory size, such as mass spectrometers, to major national facilities, such as sources of synchrotron radiation and neutrons.

This report deals solely with major facilities. That was the Committee's charge. The facilities considered were those that are national in scope, with initial costs on the order of $5-10 million or more, intended primarily for research on materials. However, materials research done on a laboratory scale is equally vital to the future strength of U.S. materials research. Support for laboratory-scale science is complementary to, not competitive with, the support for major facilities recommended in this report.

The relatively high costs of major facilities for materials research dictate that priorities be established; and the Committee in this report recommends priorities for major new facilities and new capabilities at existing facilities, for materials research and related fields. The recommended priorities involve three types of facilities, providing synchrotron radiation, neutrons, and high magnetic fields.

Synchrotron radiation, produced when energetic electrons are deflected by a magnetic field, provides over a broad spectral range the most intense source of photons now available. Such radiation can be intensified further by orders of magnitude by using insertion devices--wigglers and undulators--that put a series of sharp bends in the electron trajectories. Synchrotron-produced photons interact strongly with atomic electrons, thus, offering a means of probing the details of the electronic structure of materials.

In contrast, neutrons, which are produced by nuclear reactions, interact most strongly with atomic nucleii. Neutrons are thus uniquely suited to the study of lattice dynamics and molecular configurations. In addition, since the neutron has a magnetic moment, neutron scattering offers a unique means of probing the magnetic properties of materials. The most effective use cold neutrons, which have very low velocities, requires that they be transported through special tubes, whose walls reflect those neutrons with minimum loss, to large experimental areas called guide halls.

High magnetic fields are essential to the study of a variety of technical and fundamental problems. In particular, high magnetic field facilities are essential to the development of improved superconductors and, in turn, make it possible to construct more efficient superconducting magnets capable of achieving still higher fields.

The Committee applied the following criteria in establishing its priorities:

- The importance of each facility for frontier research in materials, and consideration of research needs of other fields, including biology, chemistry, atomic and molecular physics, plasma physics, earth science, and medical science.

- The importance of each facility for applied research in areas of national priority; that is, economic competitiveness and security.

- The availability of other, less costly alternatives for accomplishing comparable scientific, technological, and educational goals.

- The contribution of each facility to a long-term national plan for such facilities, including considerations such as capital investment, operations costs, and technical feasibility.

Additional criteria that should be considered in evaluating proposals for new facilities include:

- Technical and scientific resources at the laboratory or university site, including schools or departments in related areas.

- Access and ease of use by extramural academic, industrial, or government laboratory investigators.

- Role of the facility relative to a new or strengthened mission of its home laboratory or university.

- Potential of each facility for training scientists and engineers.

Further, new facilities to be fully effective must be dedicated, that is, used exclusively for synchrotron radiation or neutron based research. Finally, to serve the entire community optimally, the geographic distribution of facilities should generally be taken into account.

CONCLUSIONS AND RECOMMENDATIONS

The Committee's recommended priorities for major facilities--both new facilities and new capabilities at existing ones--embody two prerequisites:

- That they are accompanied by expanded support of smaller materials research programs, including related instrumentation. Research on this scale continues to provide much of the fundamental new science in the field and to train a large fraction of our scientific and technical manpower.
- That resources must be provided to operate existing user facilities productively. In addition, the approved enhancements of major synchrotron radiation facilities at the Brookhaven National Laboratory, Stanford University, and the University of Wisconsin should be completed expeditiously, since it will require several years to more than a decade before the new facilities recommended in this report can contribute to the research effort of the United States.

RECOMMENDED PRIORITIES

The Committee's recommended priorities for the development and construction of facilities during the next decade include two categories:

- Major new facilities, and
- New capabilities at existing facilities.

These categories complement one another in function, time scale, and required resources. New capabilities at existing facilities are essential for scientific and technological needs in the next decade, while the long lead times needed to construct major new synchrotron radiation and neutron facilities require that we start now with the planning and design of such new facilities. They also require that we begin immediately to implement new capabilities at existing facilities. The Committee concludes that both categories are essential for the effective evolution of science and advanced technology in the United States in the next decade and beyond.

The Committee also recommends the convening of additional panels to address other important aspects of materials research.

Major New Facilities

The Committee's recommendations for the construction of major new facilities are listed below in order of priority.

1. A 6 GeV Synchrotron Radiation Facility. This would be designed to make optimum use of the new scientific and technological opportunities presented by insertion devices. These devices, by providing radiation having orders of magnitude greater brightness than currently available, will make it possible to expand on the seminal research using synchrotron radiation carried out in the past decade. A synchrotron radiation facility with a storage ring energy of about 6 GeV will offer both identifiable and unforseeable new opportunities for research throughout the electromagnetic spectrum. It is optimal for providing radiation from undulators at about 10 keV, where most x-ray research is done. For example, the brightness increase will make it possible to investigate the properties of more complex materials and smaller samples with increased spatial and energy resolution. Site-independent design should begin immediately, and the site selection and construction should commence as soon as possible. If construction were to begin, for example, in FY 87, operation is possible by FY 92.

2. An Advanced Steady State Neutron Facility. The goal is to achieve about ten times the flux of existing machines with a minimum requirement of five times the flux. There are two principal reasons for this recommendation. First, and most important, a high-flux source can be designed to optimize beam geometry and flux distribution, so as to yield greatly increased intensities for all experiments. An increase of about ten times the flux of existing machines is an aggressive but technologically feasible goal. Such a facility would ensure the United States a leading position in this field. This is especially important in the cold neutron range, where flux increases of an order of magnitude can be achieved, providing new capability, for example, for high-resolution spectroscopy and small-angle scattering studies. Second, a new source will be a timely replacement for one or more of our existing sources built in the 1960's. Site-independent design should begin immediately. However, because of safety requirements, the Committee does not expect construction to begin until about FY 89 with completion possibly by FY 96.

3. A 1 to 2 GeV Synchrotron Radiation Facility. This facility would be centered around insertion devices but optimized for the vacuum ultraviolet (VUV) and soft x-ray region. This facility furnishes additional scientific and technical opportunities for research in chemical physics, electron spectroscopy, and imaging techniques such as microscopy and holography.

4. A High-Intensity Pulsed Neutron Facility. Pulsed neutron sources offer new scientific capabilities, especially for investigations requiring higher energy, or greater than thermal, neutrons. Also, there are practical limits to the intensity that steady state reactors can provide. Thus, future improvements in neutron sources, beyond the second priority above, will probably come from alternative approaches, the most promising of which is based on pulsed neutron

sources. However, future action on the construction of a high-intensity pulsed source (about 10^{17} neutrons/cm^2-sec peak flux) should be based upon the results obtained with lower-intensity pulsed sources.

New Capabilities at Existing Facilities

Recent developments make it both practical and cost effective to adapt certain existing user facilities to new purposes by adding experimental halls, instruments, and modified sources. These additions provide an opportunity for new frontier science; they are not simply extensions of existing work.

The Committee's recommendations in order of priority for the addition of these new capabilities at existing user facilities are:

1. Centers for Cold Neutron Research. Guide halls and instrumentation for exploiting the only cold neutron sources in the U.S. located at the Brookhaven National Laboratory and at the National Bureau of Standards, should be developed in an orderly fashion.

There is no cold neutron guide hall in the United States, and such facilities are urgently needed to address the rapid expansion of neutron applications in materials science, chemistry and biology. Many central problems in these sciences can only be solved using new instruments with cold neutron beams. These centers will enable U.S. scientists to be competitive in cold neutron research during the next decade; and they will provide new instrumentation concepts for developing future neutron scattering sources.

2. Insertion Devices on Existing Synchrotron Radiation Facilities. Insertion devices should be developed in an orderly fashion to exploit about six of the remaining straight sections of existing storage rings. The special characteristics of undulators as radiation sources should be emphasized, to use our existing capability most effectively.

Undulators on existing machines will be our premier synchrotron radiation source for the next 5 years. They will also provide valuable experience for the next generation of synchrotron radiation facilities which will also be based upon undulators. The construction of additional insertion devices, when approved, should follow the construction of new capabilities at synchrotron radiation facilities already included in the budgets for FY 85 and FY 86.

3. Experimental Hall and Instrumentation at the Los Alamos National Laboratory. An experimental hall and new instruments at the pulsed neutron source at the Los Alamos National Laboratory (LANL) would make the United States competitive in pulsed neutron research and would help guide the development of future pulsed sources.

The expected flux increase at this facility is an important opportunity to explore, at modest cost, the great promise of pulsed neutron science for spectroscopic and structural problems.

4. *Upgrading of the National Magnet Laboratory.* The need for timely development of pulsed magnetic field facilities and instrumentation enhancements at the National Magnet Laboratory has been demonstrated. This laboratory, the only major high magnetic field research facility in the United States provides a unique combination of high fields and low temperatures. Many advances in research depend on its continued development as a dedicated user facility.

5. *Enriched Pulsed Neutron Targets.* Enriched targets, by exploiting fission events to amplify the neutron flux, can more than double the available flux. The development and installation of enriched targets for use at pulsed neutron facilities would be cost effective.

Priorities 1 and 2 for major new facilities, when they are implemented, would serve as a centerpiece of this nation's future capability for synchrotron radiation and neutron based research. Thus, design and siting studies for a 6 GeV synchrotron radiation facility and for an advanced steady state neutron facility should begin immediately.

Because of the long lead time associated with an advanced steady state neutron facility, the immediate implementation of at least one instrumented cold neutron guide hall is necessary to provide forefront capability.

The basis for these conclusions is expanded upon in the body of the report. Chapter I outlines the characteristics of materials research at universities, at governmental and private laboratories, and in industry, including research styles, research organizational modes, instrumentation, and the role of national facilities. It also offers a brief summary of the status of U.S. facilities vis-a-vis those of other countries. Chapter II outlines scientific and technological accomplishments, using major materials facilities, and suggests the likely direction of future research. It presents the scientific and technological rationale for the recommendations in this report. The Committee's conclusions and recommended priorities for national facilities for materials research and related fields are given in Chapter III.

The Committee again emphasizes that, in response to its charge, its recommended priorities include only synchrotron radiation, neutron scattering, and high magnetic field facilities. Other meritorious materials research facilities were also discussed by the Committee. A number of these are briefly described in Chapters I and III.

APPENDIX B

THE SECRETARY OF ENERGY
WASHINGTON, D.C. 20585

July 2, 1984

Mr. Ralph S. Gens
Chairman
Energy Research Advisory Board
4046 SW. Jerald Court
Portland, OR 97221

Dear Mr. Gens:

The Department of Energy is one of the principal agencies of Government responsible for the support of scientific research, particularly basic research. Such research is vital to the Nation's long-range economic development and provides the intellectual underpinning for future technological development.

Four studies are presently being undertaken by the National Research Council (NRC) that have the general objective of describing the contributions and future potential of major materials facilities, chemistry, physics, and engineering. Each of these studies is a major undertaking, involving the participation and effort of large numbers of individuals from their respective scientific communities. These studies have been undertaken with the cooperation and support of the Office of Science and Technology Policy, this Department, and of other agencies of Government.

It is likely that these studies will provide advice and information that could have a major effect on the Department's science efforts over the coming years. Each area being studied concerns not only the programs of the Office of Energy Research, but also all of the other components of the Department that carry out research in the areas involved. For this reason, it would be desirable for the Energy Research Advisory Board to undertake a broadly-based review of each study as it is completed. Such a review would examine the substantive recommendations that have been made, assess their significance in terms of the Department's programs and responsibilities, and recommend to me such action as may be appropriate. These reviews would be of great assistance to the Department and would be consistent with the view, previously expressed by the Board, that studies of our basic sciences programs are needed.

It is anticipated that the NRC studies on materials facilities and chemistry will be completed by late summer and the other two somewhat later. Your views and conclusions should be made available to me within about 6 months of the completion of the NRC studies so that the Department may respond appropriately.

Thank you for taking on this important task.

Sincerely,

Donald Paul Hodel

DONALD PAUL HODEL

APPENDIX C

Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington D.C. 20585
(202) 252-8933

September 19, 1985

Dr. Arthur Hansen
Chancellor
Texas A&M University System
College Station, TX 77843

Dear Art,

As we discussed at the Los Alamos meeting, the Secretary has asked ERAB to review for the Department a series of forthcoming National Research Council reports on studies of major scientific disciplines. Given the role of your subpanel in the long-range R&D strategy study, it seems appropriate for these reviews to be undertaken under your overall direction. The information provided by these reports can then be readily incorporated in your broader deliberations.

There will probably be four such ad hoc reviews to undertake over the next year. I recognize that reviewing these in sequence is somewhat awkward, but waiting until all the studies are in hand would introduce undue delays in DOE's decision processes. When all the reviews are completed, it will then be possible to consider priorities between the various fields.

The first report to be examined is "Major Facilities for Materials and Related Disciplines" that was presented to us at Los Alamos by Dr. Frederick Seitz. That study is of particular importance since DOE provides most of the large national user facilities such as those discussed in the report. The NRC study represents the considered judgment of the scientific community on priority needs for these major facilities. Your review should consider the appropriateness and urgency of DOE implementing any of these recommendations. Each of the recommended facility upgrades and new facilities serves a somewhat different set of needs and potential users. Priorities from the DOE standpoint should consider those differences and the overall importance to the Nation. Implementation of the recommendations in this report must, in addition, take into account the timing, cost, and urgency of the various choices, and whether there are further needs or requirements that were not fully considered.

To carry out the review, I suggest selecting a subgroup from your panel, suitably augmented and balanced with outside experts knowledgeable in the DOE mission areas, and chaired by yourself or another ERAB member. This group might then be briefed by the appropriate DOE program personnel on plans in this area. It should also seek the views of others having an interest in such facilities including potential university, industry, and national laboratory project personnel or facility users.

It would be desirable to have an initial reaction from the group in time for discussion at the ERAB meeting in February 1985.

Sincerely,

Ralph S. Gens

Ralph S. Gens
Chairman

APPENDIX D

DEPARTMENT OF ENERGY
OFFICE OF ENERGY RESEARCH
ENERGY RESEARCH ADVISORY BOARD

MATERIALS FACILITIES AD HOC REVIEW
Tuesday, October 30, 1984, 9 a.m.-5 p.m.
Forrestal Building, Room 4E069
1000 Independence Avenue, SW
Washington, DC 20585

F. Stehli, Chairman

9:00	Opening Remarks	F. Stehli
9:05	Purpose of the Review	J. Snow
9:20	Synchrotron Radiation Priorities	D. Lynch
10:10	Coffee Break	
10:30	Neutron Research Priorities	R. Brugger
11:20	"Other" Facilities Priorities	
12:00	Lunch	
1:15	The National Science Foundation view	M. Bardon
1:30	The Department of Defense view	L. Young
1:45	The Department of Commerce (NBS) view	D. Johnson
2:00	The Department of Energy (BES) view	R. Kropschot
2:15	Roundtable discussion of Agencies' views	
2:40	Coffee Break	
3:00	Review Committee Discussion - Other information needs - Following meetings	F. Stehli

D-2

DEPARTMENT OF ENERGY
OFFICE OF ENERGY RESEARCH
ENERGY RESEARCH ADVISORY BOARD

MATERIALS FACILITIES AD HOC REVIEW
Wednesday, December 12, 1984, 9 a.m.-5 p.m.
Building 50, Room 5132
Lawrence Berkeley Laboratory
Berkeley, California 94720

F. Stehli, Chairman

9:00	Opening Remarks, setting of next meeting	F. Stehli
9:15	Synchrotron Radiation Prospect	M. Knotek
10:00	Coffee Break	
10:15	Neutron Research Prospect	S. Werner
11:00	Discussion of NSF response to NRC study	Telex from M. Bardon
11:30	DOE Management of Major Facilities	D. Stevens
12:00	Lunch	
1:15	Stanford	A. Bienenstock
2:00	Lawrence Berkeley	D. Shirley
2:45	Lawrence Livermore	Karl Poppe
3:15	Coffee Break	
3:30	Review Committee Discussion: Future agenda	F. Stehli

DEPARTMENT OF ENERGY
OFFICE OF ENERGY RESEARCH
ENERGY RESEARCH ADVISORY BOARD

MATERIALS FACILITIES AD HOC REVIEW
Room 2035
Hilton O'Hare Hotel
Chicago, Illinois 60666
(312)-686-8000

F. Stehli, Chairman

Friday, January 25, 1985

9:00	Opening Remarks	F. Stehli
9:15	Argonne	K. Kliewer
9:45	Oak Ridge	R. Moon
10:15	Coffee Break	
10:30	Los Alamos	J. Browne
10:50	Brookhaven	M. Blume
11:20	Discussion of Preliminary Letter Report	F. Stehli
12:20	Lunch	
1:00 - 3:30	Optional tour of the Intense Pulsed Neutron Source Facility at Argonne	
1:00 - 9:00	Discussion and Composition of Review Report	F. Stehli

Saturday, January 26, 1985

9:00 - 11:00	Composition of Review Report	F. Stehli
11:00 - 12:00	Wrap-up Session	F. Stehli

APPENDIX E

MAJOR BES USER FACILITY FUNDING AND USE -- 1985 2/21/85

The Major BES User Facilities are those designed, constructed and operated to provide a unique research capability in the United States; access to these facilities is provided to scientists conducting relevant research requiring the unique capabilities available. Many university and industrial scientists are included among the users.

The Major BES User Facilities are:

High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory
High Flux Beam Reactor (HFBR), Brookhaven National Laboratory
Intense Pulsed Neutron Source (IPNS), Argonne National Laboratory
Stanford Synchrotron Radiation Laboratory (SSRL), Stanford University
National Synchrotron Light Source (NSLS), Brookhaven National Laboratory
Pulsed Spallation Research Neutron Facility (PSR), Los Alamos National Laboratory
Combustion Research Facility (CRF), Sandia National Laboratory-Livermore
National Center for Electron Microscopy (NCEM), Lawrence Berkeley Laboratory

Note: Funding figures are for FY1985 unless otherwise noted. They are based on the FY 1985 appropriation (A) and/or information provided by the facilities (F)

(Dollars in Thousands)

SPONSORSHIP	HFIR FY85 "	HFBR FY85	IPNS FY85	SSRL FY85	NSLS FY85	WNR/PSR FY85	CRF FY85	NCEM FY85	SUB-TOTALS	TOTALS
To Operate Facility:										
From BES	6800 A	6245 A	4250 A	8040 A	13140 A	300 A	2250 A	1400 A		42425
From Other ER										0
From Other DOE	294 F									294
From Other FED Agencies	50 F									50
From Other Sources:										0
Isotope Sales/Industry	567 F		30(F,7)							597
Miscellaneous	816 F					3415(19, F)		5 F		4236
Total	8527	6245	4280	8040	13140	3715	2250	1405		47602
To Carry Out Research at Facility:										
BES Support for Services to Outside Users	1285 A	1850(15, A)	2013(F,7)	Incl in Oprtns	2190(13, A)	720 A	1125 A	50 A		9233
BES Support of Research at Lab-Direct	1445 A	3245 A	2300 A	1391	3440 A	980 A	2340 A	750 A		15891
BES Support of Research at Lab-Indirect, PRT's, etc.	570 A	190 A	375(F,7)	Incl in Oprtns	2420 F		0			3555
Other ER Support:		3000(16, F)		0	1160 F		1460(1)			5620+
Fusion Energy	1200 F								1200	
Other DOE Support:		230(17, F)		0	500 F					730+
Fossil Energy							1800		1800	
Conservation/Renewable							1800		1800	
Defense Programs				500		800 F	750	10 F	2060	
Nuclear Energy	475 F								475	
Other FED Agencies:		2100 F	475(F,7)		2240 F			50 F		4865+
Nuclear Reg. Comm.	800 F						500		1300	
NSF	755 F									
Industry	320 F	350 F	225(F,7)	0	3960 F		620(2)	180(7,F)		5655+
Foreign	665 F	1300 F	975(F,7)	0			0	20(7,F)		3040+
Other:				0			700(3)			700+
Universities	1310 F	450 F	475(F,7)					35(7,F)	2470	
Total	9025	12795	6838	1891(8)	15910	2500	11095	1095		61149

SPONSORSHIP	HFIR FY85	HFBR FY85	IPNS FY85	SSRL FY85	NSLS FY85	SNR FY85	CRF FY85	NCEM FY85	TOTAL (PEOPLE)	TOTALS OVERALL
DOE Labs - Same Site	21%	17%	33%	2%	25%	25%	60%	30%	267	18%
DOE Labs - Other Sites	6%	5%	5%	14%	8%	12%	2%	9%	143	9%
Other Government Labs	2%	2%	1%	5%		6%	3%	2%	52	3%
Universities	45%	50%	30%	41%	42%	25%	26%	30%	590	39%
Industry	9%	5%	6%	25%	20%	7%	9%	23%	241	16%
Foreign	16%	22%	26%	10%	5%	25%	0%	6%	209	14%
Others	-	-	-	2%	-				15	1%
Total	100%(6)	100%	100%(7)	100%(4,	100(14)	100%	100%(5)	100%(8)	1517	100%
Total number of Users	127	241	150	618 8)	10	100	115	66		

A Data source is FY 85 Congressional Appropriations subprogram allotments

$ Information on performers in thousands of dollars

(2) Includes $ 500 K for salary, travel, incidental costs for visiting scientists at CRF

(3) Estimated total travel, salary, incidental costs to universities, other labs for visiting scientists at CRF

(4) Officially involved experimenters, includes SSRL research staff

(5) Performers are those who spend one week or longer at CRF; % is not of MY of effort;
BES sponsored resident staff accounts for about 35 % of MY of effort

(6) Based on 127 performers at HFIR in FY 1983; includes neutron scattering users only

(7) FY 84 experience

(8) FY 83 experience

(12) Foreign users are temporarily affiliated with LBL and work on DOE NCEM projects

(13) $1540 K of this is reported as "operations to support outside users" at NSLS

(14) FY84 experience with UV ring only; total of 146 users. This will rise with x-ray ring operations

(15) $145 K of this is reported as "operations to support outside users" at HFBR

(16) A significant percent of this is also for support to outside users at HFBR

(17) Estimated DOE support to University Users at HFBR

(19) Funds allocated internally to WNR/PSR from several programs(weapons program, discretionary funds)

APPENDIX F

FACSIMILE

DATE: 12/11/84

ADDRESSEE'S NAME: Dr. F.G. Stehli, Chairman, ERAB

ADDRESSEE ORGANIZATION: Materials Facilities Ad Hoc Review Committee

STREET ADDRESS: Department of Energy

CITY, STATE, AND ZIP CODE: Washington, DC 20585

MESSAGE: Mr. Bloch has asked me to respond to your letter of November 30, 1984. I quite agree that the DOE and NSF need to assess their mutual roles in response to the NRC study, "Major Facilities for Materials Research and Related Disciplines." I am therefore quite pleased that your ad hoc review committee is taking up this important issue at its meeting on December 12, 1984, at Lawrence Berkeley Laboratory.

What follows is our understanding of the current status of the response of other Federal agencies to this report and briefly gives NSF positions in each case.

MAJOR NEW FACILITIES

1. A 6 GeV-Synchrotron Radiation Facility. DOE has set up a subcommittee of the Energy Research Advisory Board (ERAB) to make recommendations regarding the DOE response. A conference has been held at Iowa State early in October 1984 to organize exploratory design and development for this facility.

NSF POSITION: This facility is needed by the U.S. The NSF will cooperate and coordinate with DOE in this initial, site-independent exploratory design and development phase.

2. An Advanced Steady State-Neutron Facility. Preliminary design studies are underway at Oak Ridge. It is not clear that such an improvement is feasible.

NSF POSITION: This activity falls within DOE's purview.

3. A 1 to-2-GeV Synchrotron Radiation Facility. DOE has a design completed and reviewed.

NSF POSITION: Contingent upon future of Alladin Project.

4. A-High Intensity Pulsed Neutron Facility. DOE does not feel that a case exists for such a facility. They will continue to fund facilities at Los Alamos and Argonne and monitor development of research that utilizes these facilities.

NSF POSITION: This activity falls within DOE's purview.

F-2

NEW CAPABILITIES AT EXISTING FACILITIES

1. Centers for Cold Neutron Research

NBS is funded to install a cold source and to double reactor power to 20 megawatts; three experimental stations are planned (small-angle scattering, time-of-flight, depth profile analysis).

NBS will seek funding for a guide hall and a new building (approximately $25M over several years), which will permit 15 experimental stations, all to use cold neutrons.

Brookhaven will seek funding for a guide hall and a new building (approximately $25M over several years, which will permit 15 experimental stations. Only five of these will use cold neutrons. Because of existing reactor design, the Brookhaven reactor will not produce a cold neutron flux superior to the NBS reactor even though it is a 60 megawatt reactor.

NSF POSITION: These activities fall within the purview of Commerce and DOE. From a scientific point of view, the Nation needs cold neutrons. Support for NBS is warranted.

2. Insertion Devices on Existing Synchrotron Radiation Facilities. DOE is proceeding with SSRL and NSLS.

NSF POSITION: Contingent on future of Aladdin Project.

3. Experimental Hall And Instrumentation at the Los Alamos National Laboratory.

DOE will build.

4. Upgrading of the National Magnet Laboratory. NSF responsibility. An experimental station that can produce 500 kilogauss for a millisecond is operational and being used for experiments. A properly instrumented user facility will be considered if scientific opportunities warrant it.

5. Enriched Pulsed Neutron Targets. DOE will provide material for these targets if proper safeguards can be maintained.

cc: Mr. Erich Bloch

SENDER'S NAME AND TITLE: Marcel Bardon, Acting Assistant Director for
Mathematical and Physical Sciences

ORGANIZATION: National Science Foundation

PHONE AND ROOM NO. 357-9742 Room 512

COST ESTIMATE FOR LEU CONVERSION AND STANDARDIZATION OF UNIVERSITY RESEARCH AND TEST REACTOR FUELS*

OFFICE OF ENERGY RESEARCH
DEPARTMENT OF ENERGY

SUMMARY

Twenty U.S. university research reactors which currently use Highly Enriched Uranium (HEU) fuels could be required to convert to Low Enriched Uranium LEU fuels to comply with a proposed Nuclear Regulatory Commission (NRC) rule. This report provides an estimate of the cost of such conversions and uses the general data available to the Reduced Enrichment for Research and Test Reactors Program (RERTR) with additional data collected from reactor operators, fuel fabricators, and fuel shippers. The reactors are divided into three groups: (1) fourteen plate-type reactors requiring fuels with medium-uranium-density fuels, (2) four TRIGA reactors, and (3) two plate-type reactors requiring fuels with high-uranium-density. In 1985 dollars the total conversion costs of the three groups are estimated at $5,503K, $3,663K and $892K, respectively, for a grand total of $10,118K. Of the grand total, $7,157K are spent for fuel procurement, $1,968K for licensing, $525K for transportation and $468K for reactor startup. It should be noted that these are conservative estimates and do not include such things as the litigation costs due to potential licensing interventions. These costs could be substantial. In addition, there may be some structural modifications required for some of the reactors, due to the NRC rule, that are also not included in the estimates above. Conversion of these facilities, if required, would take at least five years.

1. INTRODUCTION

Pursuant to H.R. 98-755, the FY 1985 House Appropriations Committee Report on the Energy and Water Development Appropriations Bill, this report is submitted to provide estimated costs for conversion to LEU (<20%) fuel of university research reactors currently using HEU ($\geq$20%) fuel. Implementation of reactor conversions depends upon the final action taken by the Nuclear Regulatory Commission (NRC) on a Proposed Rule "Limiting the Use of Highly Enriched Uranium in Domestic Research and Test Reactors" that was published in the Federal Register (Vol. 49, No. 131, p. 27769) on July 6, 1984.

The collection of information and data for this report was coordinated by the RERTR Program at the Argonne National Laboratory (ANL). The contributors were 14 university research reactor operators, EG&G Idaho, Babcock & Wilcox and DOE.

---

*Report prepared with the assistance of A. Travelli, J. E. Matos, and J. L. Snelgrove, RERTR Program, Argonne National Laboratory; J. Kelly, B&W, K. Brown, EG&G, Idaho, and H. Young, DOE.

2. UNIVERSITY REACTORS USING HEU FUEL

Cost estimates are provided for the 16 university reactors currently using HEU plate-type fuel and for the 4 university reactors currently using HEU TRIGA-type fuel. These reactors are licensed by the NRC and are owned by the following institutions:

Table 1. University Reactors Using HEU Fuel

Plate-Type Reactors
Requiring
Medium Density LEU Fuel

1. Georgia Institute of Technology (GTRR)
2. University of Virginia (UVAR)
3. University of Virginia (UVACAV)
4. Rhode Island Atomic Energy Comm. (RINSC)
5. University of Lowell
6. University of Missouri-Rolla
7. Purdue University
8. University of Florida
9. University of Washington
10. Iowa State University
11. Worcester Polytechnic Institute
12. Ohio State University
13. Manhattan College
14. Rensselaer Polytechnic Institute

TRIGA-Type Reactors
Requiring
Medium Density LEU Fuel

15. Oregon State University
16. University of Wisconsin
17. Texas A&M University
18. Washington State University

Plate-Type Reactors
Requiring
High Density LEU Fuel

19. Massachusetts Inst. of Technology
20. University of Missouri-Columbia

The 14 plate-type and 4 TRIGA-type reactors are addressed in Sections 3 through 9. The two plate-type reactors requiring high-density fuel are addressed in Section 10.

3. INFORMATION AND DATA

Detailed information on the plate-type reactors, their Technical Specifications and Safety Analysis Reports, the HEU fuels in current use, and their possible LEU fuel needs were obtained by RERTR Program personnel on visits to six reactors during November 1984 and at meetings that were held at ANL on 3-5 December 1984 with the operators of the 14 university plate-type reactors requiring medium-density LEU fuel, EG&G Idaho, Babcock and Wilcox, and DOE. Information on the four reactors using TRIGA-type fuel was obtained from the ANS Research, Training, Test and Production Reactor Directory, Second Edition (1983).

4. LEU FUEL OPTIONS

TRIGA LEU fuel with 20 wt% U has been developed by GA Technologies as a standard replacement for its HEU (70%) Fuel Life Improvement Program (FLIP)-type fuel. This LEU fuel is fully-qualified, with burnup/pulsing limitations similar to those of FLIP fuel, for possible use in the four reactors using HEU FLIP fuel without any changes in their current fuel element geometry.

Several options were developed for the plate-type reactors using HEU fuel because their designs are more varied and there is much less standardization. The LEU fuel options considered for the plate-type reactors are based upon:

1. Minimum changes in the current fuel element geometry.
   (see Attachment 1, Table 1-1)
2. Two standard LEU plates (Michigan and Virginia).
   (see Attachment 1, Table 1-2)
3. One standard LEU plate (Michigan) with two fissile loadings.
   (see Attachment 1, Table 1-3)

All three options would utilize LEU U_3Si_2-Al fuel with a uranium density less than about 3.8 g/cm^3. The RERTR Program schedule for technical qualification of this fuel is the end of 1985.

Operators of the plate-type reactors expressed a strong preference for the option based on minimum changes in their current fuel element geometry because they believe that this option would minimize the effort required to obtain the necessary licensing approvals. This was the only option agreed upon at the ANL meetings on 3-5 December 1984.

Minimum Change Option

In the minimum change option, the number of plates per element and the dimensions of the plates would be the same with LEU fuel as with the current HEU fuel. Generally, the fissile content of the LEU plates was increased by 10-20% to compensate for the increased neutron absorption in ^{238}U. For four reactors with 60 mil thick plates (RINSC, Lowell, UM-Rolla, and Purdue), the dimensions of the fuel meat were modified so that they would be identical with the LEU fuel meat dimensions currently in use in the Ford Nuclear Reactor at the University of Michigan.

One exception in the minimum change option is the reactor at RPI. The structural materials (fuel plate cladding, fuel boxes, top and bottom grid plates, etc.) are all composed of stainless steel. It is feasible to use 50 mil or 60 mil aluminum clad LEU plates with the existing stainless steel structural components or with new aluminum structural components if a demineralizer is also installed. However, it seems reasonable to consider utilizing the stainless steel clad Special Power Excursion Reactor Test (SPERT) fuel pins with 4.8% enriched UO_2 pellets that are currently in storage at the University of Florida.

Standard Fuel Plate Options

Options 2 and 3 using standard LEU fuel plates were developed by the RERTR Program at the request of DOE. In the 1950's and 1960's the procurement procedures for university research reactors using plate-type fuels resulted in a variety of designs for the same basic type of reactor. Many of the differences in the designs of the fuel elements do not affect the safety or operation of the reactors, but they do increase the cost of procuring fuel. For this reason, DOE is considering standardizing the designs of the fuel plates and, to the extent possible, the design of the entire fuel elements. The options developed here address standardization of the fuel plate designs. The extent of possible standardization of entire fuel element design is under further study by the fuel fabrication contractor (Babcock and Wilcox).

Option 2 considers two standard fuel plates: one based on the 50 mil thick fuel plates currently in use in the University of Virginia reactors, but containing U_3Si_2-Al fuel meat with 3.75 g U/cm^3, and the second based on the 60 mil thick LEU fuel plates currently in use in the University of Michigan reactor, but with U_3Si_2-Al fuel meat instead of UAl_x-Al fuel meat. Six reactors are listed in Attachment 2, Table 2-2 as candidates for use of a standard LEU Virginia plate and six reactors are listed as candidates for use of a standard LEU Michigan plate. RPI as well as Manhattan College would retain unique fuel element designs with this option.

Option 3 is similar to Option 2, but considers the 60 mil thick Michigan LEU fuel plate as a standard. However, two uranium densities (1.8 g U/cm^3 and 2.4 g U/cm^3) are needed to accommodate the fissile loading requirements of the various reactors.

5. COST COMPONENTS

The four cost components that were considered are:

- PROCUREMENT OF LEU FUEL ELEMENTS
  - Preparation of Fuel Element Specifications
  - Fuel Element Fabrication
- LICENSING ISSUES
  - Revision of Technical Specifications
  - Revision of Safety Analysis Reports
  - Interactions with NRC
- TRANSPORTATION
  - Ship Irradiated and Fresh HEU Fuel from Reactor to Designated DOE Sites
  - Ship Fresh LEU Fuel from Fabricator to Reactor
- REACTOR STARTUP
  - Characterization of LEU Core
  - Recalibration of Experimental Equipment

For the 18 university reactors requiring medium-density LEU fuels, these four components and the rationale involved are discussed in Sections 6 through 9. For the two reactors requiring high-density LEU fuels, the breakdown of the estimated costs is discussed in Section 10.

6. PROCUREMENT OF LEU FUEL ELEMENTS

Cost estimates for LEU fuel procurement for each of the 14 plate-type reactors were provided by Babcock and Wilcox and EG&G Idaho based on examinations of the fuel plate and fuel element drawings that were provided by each of the reactor operators at the ANL meetings on 3-5 December 1984. However, since all of the information that would be needed by B&W and EG&G Idaho for actual fuel procurement was not available, these cost estimates must be regarded as preliminary and do not represent a formal cost proposal. Additionally, the data provided by B&W was modified slightly by DOE and the RERTR Program staff for consistency with the number of LEU elements and fuel plate fissile loadings quoted in this report.

Cost data for the TRIGA-type fuel elements were provided by EG&G Idaho based on GA Technologies' current Domestic Fuel Price List (Gen-11, 15 June 1984) and on discussions with GA fuel procurement personnel. U.S. Government charges for conversion of UF_6 to U metal and a GA handling charge have been included in the estimated costs.

The total costs ($000) were estimated to be:

Reactors	Based on Minimum Changes	Based on Standard LEU Plates
14 Plate-Type	3630	3815
4 TRIGA-Type	2962	2962
	6592	6777

Cost breakdowns by reactor are provided in Tables 2 and 3 for options based on minimum changes in the current fuel element geometry and on use of standard LEU fuel plate designs. Additional details are shown in Tables 1-4 and 1-5 of Attachment 1.

Estimated costs for the options with standard plates are higher by $185K than those with minimum changes in the current fuel element geometry because seven reactors would require 3108 standard fuel plates instead of 1851 non-standard fuel plates to achieve the required fissile content per element. The higher fuel plate fabrication yield for the standard plates does not fully compensate the large increase in the number of plates that would be needed. However, licensing costs could be lower with standardized fuel plate and fuel element designs.

Table 2.

LEU Fuel Procurement Cost ($000) Estimate
Based on Minimum Changes in Current Fuel Element Geometry

	Reactor	No. of Elements	Setup Cost	Manuf. Cost	Sub-total	Procurement Management	Total
			Plate-Type Reactors				
1.	GTRR	37	55	247	302	31	333
2.-3.	UVAR & UVA CAV	40	28	286	314	31	345
4.-5.	RINSC & Lowell	84	31	588	619	49	668
6.	UM-Rolla	28	28	152	180	23	203
7.	Purdue	16	28	102	130	21	151
8.	Florida	44	28	239	267	28	295
9.	Washington	26	28	145	173	23	196
10.	Iowa State	15	28	99	127	20	147
11.	WPI	30	36	193	229	26	255
12.	Ohio State	29	36	188	224	26	250
13.	Manhattan College	16	242	156	398	36	434
		365	568	2395	2963	314	3277
14.	RPI	~25	(SPERT Pins)		320	33	353
	Subtotal (Plate-type)	390			3283	347	3630
			TRIGA-Type Reactors				
15.	Oregon State	91			602	35	637
16.	Wisconsin	27			715	42	757
17.	Texas A&M	27			696	40	736
18.	Washington State	30			786	46	832
	Subtotal (TRIGA-type)				2799	163	2962
	TOTAL				6082	510	6592

Table 3.

LEU Fuel Procurement Cost ($000) Estimate
Based on Two Standard Fuel Plates or One Standard Fuel
Plate With Two Fissile Loadings

	Reactor	No. of Elements	Setup Cost	Manuf. Cost	Sub-total	Procurement Management	Total
			Plate-Type Reactors				
1.	GTRR	37	55	247	302	31	333
2.-3.	UVAR & UVA CAV	40	28	286	314	31	345
4.-5.	RINSC & Lowell	84	31	588	619	49	668
6.	UM-Rolla	33	21	219	240	27	267
7.	Purdue	16	21	131	152	22	174
8.	Florida	44	21	292	313	31	344
9.	Washington	26	21	178	199	25	224
10.	Iowa State	15	21	130	151	22	173
11.	WPI	30	21	207	228	26	254
12.	Ohio State	29	21	199	220	26	246
13.	Manhattan College	16	242	156	398	36	434
		370	503	2633	3136	326	3462
14.	RPI	~25	(SPERT Pins)		320	33	353
	Subtotal (Plate-type)	395			3456	359	3815
			TRIGA-Type Reactors				
15.	Oregon State	91			602	35	637
16.	Wisconsin	27			715	42	757
17.	Texas A&M	27			696	40	736
18.	Washington State	30			786	46	832
	Subtotal (TRIGA-type)				2799	163	2962
	TOTAL				6255	522	6777

7. LICENSING ISSUES

The actual cost of licensing university research reactor conversions from HEU to LEU fuel will depend on the actions and requirements of the NRC. Since these have not been finalized at the present time, an estimated range of licensing costs for the 14 university plate-type reactors and the 4 university TRIGA-type reactors is provided in Table 4, based on $8K per man-month of effort. The cost of litigation due to possible interventions has not been included. However, as an example, it is illustrative to look at the relicensing of UCLA's research reactor. The intervention process on the relicensing of UCLA's 100KW Argonaut reactor was initiated in September, 1980, and continued through December, 1983. Participation in this process cost UCLA an estimated $401,000 in non-reimbursable expenditures. This amount does not include an additional $30,000 expended for licensing preparation and reproduction prior to the intervention. The UCLA reactor is currently in the process of being decommissioned.

The estimated licensing costs in Table 4 range from $456K - $1152K for the 14 plate-type reactors and from $96K - $384K for the 4 TRIGA-type reactors. The resulting total cost range would then be $552K - $1536K.

8. TRANSPORTATION

Estimated costs of shipping irradiated and fresh HEU fuel from university reactor sites and shipping fresh LEU fuel to the sites are shown in Table 5. Additional data are provided in Attachment 1, Table 1-7. For cost estimation purposes, it was assumed that all plate-type fuel (except that from the University of Washington) would be shipped to the Savannah River Plant (SRP) and that all other fuel would be shipped to the Idaho Chemical Processing Plant (ICPP). The DOE-owned MH-1A cask will be used for shipments to SRP, and the DOE-owned HFIR cask will be used for shipments to ICPP, except for shipments of some long TRIGA rods in the GE T-2 cask. Estimated rental charges for the GE cask are included under preparations. Transportation was assumed to be provided by Tri-State Motor Transport Company and to be coordinated to reduce deadhead charges. Mileages and rates were supplied by Tri-State. The need for low-level waste (LLW) disposal results from cutting of elements to 25-in. lengths so that 32 can be shipped at one time in the MH-1A cask and from the disassembly of TRIGA clusters at three facilities. The four TRIGA facilities account for a disproportionate share of the shipping costs because of the length of time to load the casks and number of shipments required for the approximately 96 rods at each facility and because of longer distances from the reactor to ICPP.

The total costs were estimated to be $272K for the 14 plate-type reactors and $253K for the 4 TRIGA-type reactors, resulting in a total transportation cost estimate of $525K.

Table 4.

Licensing Cost ($000) Estimate

	Reactor	Man-Months	Cost ($000) Range
	Plate-Type Reactors		
1.	GTRR	6 - 12	48 - 96
2.	UVAR	6 - 12	48 - 96
3.	UVA CAV	3 - 9	24 - 72
4.	RINSC	6 - 12	48 - 96
5.	Lowell	3 - 9	24 - 72
6.	UM-Rolla	3 - 9	24 - 72
7.	Purdue	3 - 9	24 - 72
8.	Florida	3 - 9	24 - 72
9.	Washington	3 - 9	24 - 72
10.	Iowa State	3 - 9	24 - 72
11.	WPI	3 - 9	24 - 72
12.	Ohio State	3 - 9	24 - 72
13.	Manhattan College	3 - 9	24 - 72
14.	RPI	9 - 18	72 - 144
	Subtotal (Plate-Type)	57 - 144	456 - 1152
	TRIGA-Type Reactors		
15.	Oregon State	3 - 12	24 - 96
16.	Wisconsin	3 - 12	24 - 96
17.	Texas A&M	3 - 12	24 - 96
18.	Washington State	3 - 12	24 - 96
	Subtotal (TRIGA-Type)	12 - 48	96 - 384
	TOTAL	69 - 192	552 - 1536

Table 5.

Transportation Cost ($000) Estimate for Irradiated and Fresh HEU Fuel and Fresh LEU Fuel

	Reactor	No. of HEU Elements Irrad.	No. of HEU Elements Fresh	Prep. for Shipping HEU Elements	Transport Costs for HEU Elements	Apportioned Costs*	Total
	Plate-Type Reactors						
1.	GTRR	20	24	4.9	5.6	10.8	21.3
2.-3.	UVAR & UVA CAV	88	0	9.9	11.8	11.0	32.7
4.	RINSC	64	6	6.9	14.4	10.9	32.2
5.	Lowell	38	6	4.6	9.5	10.9	25.0
6.	UM-Rolla	33	0	6.0	6.1	10.8	22.9
7.	Purdue	16	2[a]	4.0	5.4	10.8	20.2
8.	Florida	23	5[a]	4.4	4.1	10.8	19.3
9.	Washington	26	2[a]	4.4	6.5	10.8	21.7
10.	Iowa State	13	4[a]	4.0	7.1	10.8	21.9
11.	WPI	26	2[a]	4.4	7.2	10.8	22.4
12.	Ohio State	29	0	5.2	5.2	10.8	21.2
13.	Manhattan College	16[b]	0	0.5	2.0	3.0	5.5
14.	RPI	25[b]	0	0.5	2.0	3.0	5.5
	Subtotal (Plate-Type)	417	51	59.7	86.9	125.2	271.8
	TRIGA-Type Reactors						
15.	Oregon State	24[c]	3[c]	18.2	27.4	10.8	56.4
16.	Wisconsin	24[c]	4[c]	18.2	40.4	10.8	69.4
17.	Texas A&M	24[c]	1[c]	18.2	42.0	10.8	71.0
18.	Washington State	24[c]	3[c]	18.2	27.4	10.8	56.4
	Subtotal (TRIGA-type)	96	11	72.8	137.2	43.2	253.2
	TOTALS	513	62	132.5	224.1	168.4	525.0

*Apportioned Costs

I.	Overall Planning and Coordination	25.7
II.	Special Handling Equipment	5.0
III.	Shipping Fresh LEU Fuel	30.0
IV.	Contingency	60.0
V.	10% Management Fee	47.7
	Total Apportioned Costs	168.4

Notes:

[a] Assumed to be shipped with irradiated fuel.

[b] Assumed to be shipped as fresh fuel because of essentially zero burnup.

[c] Shipped as four individual rods per equivalent four-rod cluster.

Table 6.

Reactor Startup Cost ($000) Estimate

	Reactor	Man-Months	Cost ($000) Range
	Plate-Type Reactors		
1.	GTRR	1 - 3	8 - 24
2.	UVAR	1 - 3	8 - 24
3.	UVA CAV	1 - 2	8 - 16
4.	RINSC	1 - 3	8 - 24
5.	Lowell	1 - 3	8 - 24
6.	UM-Rolla	1 - 2	8 - 16
7.	Purdue	1 - 2	8 - 16
8.	Florida	1 - 2	8 - 16
9.	Washington	1 - 2	8 - 16
10.	Iowa State	1 - 2	8 - 16
11.	WPI	1 - 2	8 - 16
12.	Ohio State	1 - 2	8 - 16
13.	Manhattan College	1 - 2	8 - 16
14.	RPI	2 - 3	16 - 24
	Subtotal (Plate-Type)	15 - 33	120 - 264
	TRIGA-Type Reactors		
15.	Oregon State	1 - 2	8 - 16
16.	Wisconsin	1 - 2	8 - 16
17.	Texas A&M	1 - 2	8 - 16
18.	Washington State	1 - 2	8 - 16
	Subtotal (TRIGA-Type)	4 - 8	32 - 64
	TOTAL	19 - 41	152 - 328

9. REACTOR STARTUP

University reactor operators would need to determine the operating parameters and characteristics of the new LEU cores and to recalibrate their experimental equipment. The cost range (Table 6) for this work at the universities is estimated to be \$120K - \$264K for the 14 plate-type reactors and \$32K - \$64K for the 4 TRIGA-type reactors, resulting in a total cost of \$152K - \$328K.

10. COST ESTIMATES FOR CONVERSION OF UNIVERSITY RESEARCH REACTORS REQUIRING HIGH-DENSITY FUELS

The Massachusetts Institute of Technology Reactor (MITR, 5 MW) and the University of Missouri Research Reactor (MURR, 10 MW) are assumed by the NRC to be special cases among the university reactors.

These reactors employ advanced thermalhydraulic designs and the highest uranium density currently in use with HEU fuels (1.7 g U/cm$\underline{3}$). Their conversion to LEU would require use of the most advanced fuels under development by the RERTR Program, coupled with specific changes in the design of the fuel elements. Detailed cost estimates for the conversion of MITR and MURR to fuels with <20% enrichment, or with other enrichments as may be required by the NRC, can be established only after further progress of the RERTR fuel development effort and after extensive studies to determine the feasibility and characteristics of the conversions.

For the purpose of this study, a rough estimate of the costs which the MITR and MURR conversions might entail was prepared using the following assumptions:

1. A silicide fuel with high uranium density should be successfully qualified with burnups adequate for its utilization in these reactors (1989, according to current RERTR schedules as approved by DOE).

2. Prior to qualification of this high uranium density fuel, feasibility studies would have to address its utilization in both reactors with LEU and, if needed, with other enrichments less than 93%. The studies would optimize fuel element designs within existing performance/economics/safety constraints.

3. If the feasibility studies indicate that the conversions could be achieved, then safety analysis reports would be prepared.

4. If conversion were implemented, it is assumed that the reduced enrichment fuel would be introduced in these reactors during normal refueling operations, so that the current HEU fuel would be fully utilized. This means that fuel fabrication costs would be limited to setup costs and the incremental fabrication costs of the first reduced-enrichment core.

5. Startup costs would be necessarily higher than those of reactors with lesser power because they would include loss of revenue during startup tests.

Table 7.

Summary of Conversion Costs for University Reactors Requiring High-Density Fuels

Reactor No.	Reactor Name	Fuel Fab Setup	Fuel Fab. (incremental)	Feasibility Study	Licensing	Startup Tests	Total
19	MITR	60	120	96	96	60	432
20	MURR	120	80	96	144	80	520
Totals		180	200	192	240	140	952

11. CONCLUSION

The twenty university reactors which currently use HEU fuel can be organized into three groups.

The first group includes the fourteen plate-type reactors for which LEU conversions are technically feasible with fuels of medium-uranium-density (<4.8 g U/cm^3). LEU U_3Si_2 - Al fuels of this density are not scheduled for qualification until the end of 1985. The main options for conversion of these reactors are well defined and preliminary cost estimates for fuel procurement were obtained from Babcock and Wilcox/EG&G Idaho. Three options with different degrees of standarization were considered. In the first option, all but one reactor would maintain its current fuel geometry. With the other options, all reactors with the exception of two would use one of two standard fuel plates. In general, the total conversion costs were found to be about the same in all three options.

The second group includes the four reactors using TRIGA-type fuel. The conversion option considered for this group was a direct replacement of the current HEU fuel with 20/20 TRIGA fuel having the identical geometry (20% enrichment, 20 wt.%U). This fuel has passed qualification tests comparable to those of the HEU FLIP fuel which it is meant to replace, and GA Technologies offers it at fixed catalogue prices with their standard commercial guarantee.

The third group includes two high-performance university reactors (MITR and MURR) which currently use HEU with the highest available uranium density and with advanced thermalhydraulics designs. Detailed cost estimates for this group would require further RERTR fuel development efforts and feasibility studies to identify the available options. For the purpose of this study, a rough estimate of the costs was derived on the basis of simple assumptions, with the intent of at least addressing the issue.

A summary of the overall costs for each reactor, and for each group, is provided in Table 8.

The fuel procurement costs listed for the first group correspond to the standardization option, which is slightly more expensive than the minimum-change option. The reactors in this group would cost an average of approximately \$390K each to convert, with a standard deviation of about \$90K. The costliest members of this group are the two reactors with the lowest power (Manhattan College and RPI) because of their unusual element types.

The TRIGA reactors in the second group are much more expensive to convert. Their conversions cost approximately \$920K $\geq$ 80K each, on the average, with fuel fabrication costs being the dominant component.

The average conversion costs of the third group are about \$450K per reactor. Only incremental fuel costs are considered in this case, because of the high fuel utilization rate and the long lead-time available.

Finally, standardization of the fuel elements for university research reactors has the potential of reducing the costs of future fuel procurements, but the extent of such reductions will require more detailed cost estimates from the fuel fabricator and a review of the NRC's licensing philosophy and procedures for LEU conversion.

In summary, the total conversion costs of the 20 university research reactors is about \$10 million. Of these, \$7 million are for procurement of LEU fuel, \$2 million are for licensing, and \$0.5 million each are for transportation and reactor startup.

All costs mentioned in this report are in 1985 dollars.

Table 8.

Summary of LEU Conversion Costs For University Reactors ($000)

Reactor No.	Name	Fuel Proc.	Licens-ing	Transport	Startup	Total
1.	GTRR	333	96	21	24	474
2.-3.	UVaR, UVaC	345	168	33	40	586
4.-5.	RINSC, ULR	668	168	57	48	941
6.	UMo-Rolla	267	72	23	16	378
7.	Purdue	174	72	20	16	282
8.	Florida	344	72	19	16	451
9.	Washington	224	72	22	16	334
10.	Iowa State	173	72	22	16	283
11.	WPI	254	72	22	16	364
12.	Ohio State	246	72	21	16	355
13.	Manhattan C	434	72	6	16	528
14.	RPI	353	144	6	24	527
Subtotals: Plate-type, med. density		3,815	1,152	272	264	5,503
15.	Oregon	637	96	56	16	805
16.	Wisconsin	757	96	70	16	939
17.	Texas A&M	736	96	71	16	919
18.	Wash. State	832	96	56	16	1,000
Subtotals: TRIGA-type, med. density		2,962	384	253	64	3,663
19.	MITR*	180	192	0	60	432
20.	MURR*	200	240	0	80	520
Subtotals: Plate-type, high density		380	432	0	140	932
GRAND TOTALS		7,157	1,968	525	468	10,118

* Only incremental conversion costs are considered for these reactors.

Attachment 1

DETAILED DATA ON
LEU FUEL OPTIONS
AND ESTIMATED COSTS

Table 1.1

SUMMARY - UNIVERSITY PLATE-TYPE REACTORS

LEU OPTION I

MINIMUM CHANGES IN CURRENT FUEL ELEMENT GEOMETRY

	Reactor	Power, MW	No. Els. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mils	Clad Thick., mils	Fuel Meat (Min.-Max.)			Plate Width in.	Element Cross Section in.^{2}
											Thick., mils	Width in.	Length in.		
1.	GTRR	5	17	Alloy	0.66	16*	188	11.75	50	15	20	2.5	23.0-24.0	2.871	2.96 × 2.77
	LEU:			U_3Si_2	3.74		200	12.5				2.04-2.40	22.5-24.0		
2.	UVAR	2	~20	UAl_x	0.69	18	195	10.83	50	15	20	2.04-2.40	22.5-24.0	2.775	2.94 × 3.25
	LEU:			U_3Si_2	3.74		225	12.5							
3.	UV CAV.	10^{-5}	~16	UAl_x	0.69	18	195	10.83	50	15	20	2.04-2.40	22.5-24.0	2.775	2.94 × 3.25
	LEU:			U_3Si_2	3.74		225	12.5							
4.	RINSC	2	30	UAl_x	0.72	18	124	6.9	60	24	12	2.05-2.40	22.0-23.5	2.81	3.00 × 3.00
	LEU:			U_3Si_2	1.77		167	9.3		15	30	2.14-2.50	22.5-24.0		
5.	ULR	1	26	UAl_x	0.72	18	135	6.9	60	24	12	2.05-2.40	22.0-23.5	2.81	3.00 × 3.00
	LEU:			U_3Si_2	1.77		167	9.3		15	30	2.14-2.50	22.5-24.0		
6.	UM-Rolla	0.2	19	U_3O_8	0.94	10	170	17.0	60	20	20	2.48	23.5	2.816	2.98 × 3.16(?)
	LEU:			U_3Si_2	3.73		196	19.6		15	30	2.14-2.50	22.5-24.0		
7.	Purdue	10^{-3}	16	Alloy	0.92	8-10	132-165	16.5	60	20	20	2.468	23.625	2.765	2.96 × 2.96
	LEU:			U_3Si_2	3.15					15	30	2.14-2.50	22.5-24.0		
8.	U. Fla.	0.1	21	Alloy	0.43	11	160	14.5	70	15	40	2.3	23.86	2.845	2.84 × 2.39
	LEU:			U_3Si_2	2.31		180	16.4							
9.	U. Wash.	0.1	24	Alloy	0.41	11	146	13.3	70	15	40	2.25	23.75	2.845	2.845 × 2.39
	LEU:			U_3Si_2	2.10		165	15.0							
10.	Ia. St.	10^{-2}	12	Alloy	0.61	12	264	22.0	80	20	40	2.75	23.0	3.00	3.00 × 5.54
	LEU:			U_3Si_2	3.05		300	25.0							

---

*Element has 16 Fueled and 2 Non-Fueled Plates

Table 1.1 (Cont'd.)

SUMMARY - UNIVERSITY PLATE-TYPE REACTORS

LEU OPTION I

MINIMUM CHANGES IN CURRENT FUEL ELEMENT GEOMETRY

Reactor	Power, MW	No. Ele. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mils	Clad Thick., mils	Fuel Meat (Min.-Max.) Thick., mils	Fuel Meat (Min.-Max.) Width in.	Fuel Meat (Min.-Max.) Length in.	Plate Width in.	Element Cross Section $in.^2$
11. WPI	10^{-2}	24	Alloy	0.38	10	136	13.6	99	30	39	2.50(?)	24.0	2.79(?)	3.047 × 3.047
LEU:			U_3Si_2	2.09		162	16.2	100		40				
12. OSU	10^{-2}	24	Alloy	0.44	10	140	14.0	108	36	36	2.437	24.0	2.877	3.00 × 3.00
LEU:			U_3Si_2	2.45		167	16.7							
13. M.C.	10^{-7}	16	Alloy	0.71	18[b]	200	Var.	50	15	20	Var.	24.0	Var.	3.5 in. O.D.
LEU:		.	U_3Si_2	3.84		230								
14. RPI	$<10^{-4}$	21	UO_2-SS	1.82	4-11	Var.	28.52	30	5(SS)	20	2.54	21.75	2.77	2.86 × 2.86
		4	UO_2-SS	1.80	6	161.7	27.07	30	5(SS)	20	2.32	21.125	2.55	2.86 × 2.86
LEU: SPERT Pins, 4.8% Enrichment, SS cladding														
19. MURR	10	8	UAl_x	~1.6	24	780	Var.	50	15	30	Var.	24.0	Var.	Pie Shaped
LEU Options Require Feasibility Study														
20. MIT	5	~24	UAl_x	~1.6	15	510	34.0	60	15	30	2.08	22.38	2.53	Rhomboid
LEU Options Require Feasibility Study														
FNR-LEU	2	~30	UAl_x	1.77	18	167	9.3	60	15	30	2.14-2.50	22.5-24.0	2.775	2.94 × 3.25

---

[b] Cylindrical elements with 6 concentric rings (3 plates each) per element.

Table 1.2

SUMMARY - UNIVERSITY PLATE-TYPE REACTORS
LEU OPTION 2
BASED ON TWO STANDARD PLATES (VIRGINIA AND MICHIGAN)

Reactor	Power, MW	No. Ele. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mils	Clad Thick., mils	Fuel Meat (Min.-Max.) Thick., mils	Fuel Meat (Min.-Max.) Width in.	Fuel Meat (Min.-Max.) Length in.	Plate Width in.	Element Cross Section $in.^2$
						Standard Plate: UVAR (Virginia)								
1. GTRR	5	17	Alloy	0.66	16[a]	188	11.75	50	15	20	2.5	23.0-24.0	2.871	2.96 x 2.77
LEU:			U_3Si_2	3.74		200	12.5				2.04-2.40	22.5-24.0		
2. UVAR	2	~20	UAl_x	0.69	18	195	10.83	50	15	20	2.04-2.40[b]	22.5-24.0	2.775	2.94 x 3.25
LEU:			U_3Si_2	3.74		225	12.5							
3. UV CAV.	10^{-6}	~16	UAl_x	0.68	18	195	10.83	50	15	20	2.04-2.40	22.5-24.0	2.775	2.94 x 3.25
LEU:			U_3Si_2	3.74		225	12.5							
4. U. Fla.	0.1	21	Alloy	0.43	11	160	14.5	70	15	40	2.3	23.86	2.845	2.86 x 2.39
LEU:			U_3Si_2	3.74	14	175	12.5	50		20	2.04-2.40	22.5-24.0		
5. U. Wash.	0.1	26	Alloy	0.41	11	146	13.3	70	15	40	2.25	23.75	2.845	2.845 x 2.39
LEU:			U_3Si_2	3.74	14	175	12.5	50		20	2.04-2.40	22.5-24.0		
6. Ia. St.	10^{-2}	12	Alloy	0.61	12	264	22.0	80	20	40	2.75	23.0	3.00	3.00 x 5.54
LEU:			U_3Si_2	3.74	24	300	12.5	50	15	20	2.04-2.40	22.5-24.0		
						Standard Plate: FNR (Michigan)								
7. RINSC	2	30	UAl_x	0.72	18	124	6.9	60	24	12	2.05-2.40	22.0-23.5	2.81	3.00 x 3.00
LEU:			U_3Si_2	1.77		167	9.3		15	30	2.14-2.50	22.5-24.0		
8. ULR	1	26	UAl_x	0.72	18	135	6.9	60	24	12	2.05-2.40	22.0-23.5	2.81	3.00 x 3.00
LEU:			U_3Si_2	1.77		167	9.3		15	30	2.14-2.50	22.5-24.0		
9. UM-Rolla	0.2	19	U_3O_8	0.94	10	170	17.0	60	20	20	2.48	23.5	2.816	2.98 x 3.16(?)
LEU:		~26	U_3Si_2	1.77	18	167	9.3		15	30	2.14-2.50	22.5-24.0		
10. Purdue	10^{-3}	16	Alloy	0.92	8-10	132-165	16.5	60	20	20	2.468	23.625	2.765	2.96 x 2.96
LEU:			U_3Si_2	1.77	15-18	140-167	9.3		15	30	2.14-2.50	22.5-24.0		

---

[a] Element has 16 Fueled and 2 Non-Fueled Plates.

[b] If this dimension could be changed to 2.14 - 2.50, UVAR would have the same fuel meat dimensions as FNR, but with 20 mil thick meat instead of 30 mil thick meat.

Table 1.2 (Cont'd.)

SUMMARY - UNIVERSITY PLATE-TYPE REACTORS

LEU OPTION 2

BASED ON TWO STANDARD PLATES (VIRGINIA AND MICHIGAN)

Reactor	Power, MW	No. Ele. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mils	Clad Thick., mils	Fuel Meat (Min.-Max.)			Plate Width in.	Element Cross Section in.^{2}
										Thick., mils	Width in.	Length in.		
Standard Plate: FNR (Michigan)														
11. WPI	10^{-2}	24	Alloy	0.38	10	136	13.6	99	30	39	2.50(?)	24.0	2.79(?)	3.047 × 3.047
LEU:			U_3Si_2	1.77	18	167	9.3	60	15	30	2.16-2.50	22.5-24.0		
12. OSU	10^{-2}	24	Alloy	0.44	10	140	14.0	108	36	36	2.437	24.0	2.877	3.00 × 3.00
LEU:			U_3Si_2	1.77	18	167	9.3	60	15	30	2.16-2.50	22.5-24.0		
Unique Reactors														
13. N.C.	10^{-7}	16	Alloy	0.71	18^c	200	Var.	50	15	20	Var.	24.0	Var.	3.5 in. O.D.
LEU:			U_3Si_2	3.84		230								
14. RPI	$<10^{-4}$	21	UO_2-SS	1.82	4-11	Var.	28.62	30	5(SS)	20	2.54	21.75	2.77	2.86 × 2.86
		6	UO_2-SS	1.80	6	161.7	27.07	30	5(SS)	20	2.32	21.125	2.55	2.86 × 2.86
LEU: SPERT Pins, 4.8% Enrichment, SS cladding														
19. MURR	10	8	UAl_x	~1.6	24	780	Var.	50	15	20	Var.	24.0	Var.	Pie Shaped
LEU Options Require Feasibility Study														
20. MIT	5	~24	UAl_x	~1.6	15	510	34.0	60	15	30	2.08	22.38	2.53	Rhomboid
LEU Options Require Feasibility Study														
FNR-LEU	2	~30	UAl_x	1.77	18	167	9.3	60	15	30	2.16-2.50	22.5-24.0	2.775	2.96 × 3.25

[c] Cylindrical elements with 6 concentric rings (3 plates each) per element.

Table 1.3

SUMMARY - UNIVERSITY PLATE-TYPE REACTORS
LEU OPTION 3
BASED ON ONE STANDARD PLATE (MICHIGAN) WITH TWO FISSILE LOADINGS

	Reactor	Power, MW	No. Els. in Core	Fuel Type	U Dens., g/cm^3	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mils	Clad Thick., mils	Fuel Meat (Min.-Max.) Thick., mils	Fuel Meat (Min.-Max.) Width in.	Fuel Meat (Min.-Max.) Length in.	Plate Width in.	Element Cross Section $in.^2$
						Standard Plate:	FNR (Michigan) with 2.39 g U/cm^3								
1.	GTRR	5	17	Alloy	0.66	16[a]	188	11.75	50	15	20	2.5	23.0-24.0	2.871	2.96 × 2.77
	LEU:			U_3Si_2	2.39		200	12.5	60		30	2.14-2.50	22.5-24.0		
2.	UVAR	2	~20	UAl_x	0.69	18	195	10.83	50	15	20	2.04-2.40	22.5-24.0	2.775	2.94 × 3.25
	LEU:			U_3Si_2	2.39		225	12.5	60		30	2.14-2.50			
3.	UV CAV.	10^{-4}	~16	UAl_x	0.68	18	195	10.83	50	15	20	2.04-2.40	22.5-24.0	2.775	2.94 × 3.25
	LEU:			U_3Si_2	2.39		225	12.5	60		30	2.14-2.50			
4.	U. Fla.	0.1	21	Alloy	0.43	11	160	14.5	70	15	40	2.3	23.86	2.845	2.84 × 2.39
	LEU:			U_3Si_2	2.39	14	175	12.5	60		30	2.14-2.50	22.5-24.0		
5.	U. Wash.	0.1	24	Alloy	0.41	11	146	13.3	70	15	40	2.25	23.75	2.845	2.845 × 2.39
	LEU:			U_3Si_2	2.39	14	175	12.5	60		30	2.14-2.50	22.5-24.0		
6.	Ia. St.	10^{-2}	12	Alloy	0.61	12	264	22.0	80	20	40	2.75	23.0	3.00	3.00 × 5.54
	LEU:			U_3Si_2	2.39	24	300	12.5	60	15	30	2.14-2.50	22.5-24.0		
						Standard Plate:	FNR (Michigan) with 1.77 g U/cm^3								
7.	RINSC	2	30	UAl_x	0.72	18	124	6.9	60	24	12	2.05-2.40	22.0-23.5	2.81	3.00 × 3.00
	LEU:			U_3Si_2	1.77		167	9.3		15	30	2.14-2.50	22.5-24.0		
8.	ULR	1	26	UAl_x	0.72	18	135	6.9	60	24	12	2.05-2.40	22.0-23.5	2.81	3.00 × 3.00
	LEU:			U_3Si_2	1.77		167	9.3		15	30	2.14-2.50	22.5-24.0		
9.	UM-Rolla	0.2	19	U_3O_8	0.94	10	170	17.0	60	20	20	2.48	23.5	2.816	2.98 × 3.16(?)
	LEU:		~24	U_3Si_2	1.77	18	167	9.3		15	30	2.14-2.50	22.5-24.0		
10.	Purdue	10^{-3}	16	Alloy	0.92	8-10	132-165	16.5	60	20	20	2.468	23.625	2.765	2.96 × 2.96
	LEU:			U_3Si_2	1.77	15-18	140-167	9.3		15	30	2.14-2.50	22.5-24.0		

---

[a] Element has 16 Fueled and 2 Non-Fueled Plates.

Table 1.3 (Cont'd.)

SUMMARY - UNIVERSITY PLATE-TYPE REACTORS

LEU OPTION 3

BASED ON ONE STANDARD PLATES (MICHIGAN) WITH TWO FISSILE LOADINGS

Reactor	Power, MW	No. Ele. in Core	Fuel Type	U Dens., g/cm³	Plates per Element	g^5 per El.	g^5 per Plate	Plate Thick., mils	Clad Thick., mils	Fuel Meat (Min.-Max.)			Plate Width in.	Element Cross Section in.²
										Thick., mils	Width in.	Length in.		
Standard Plate: FNR (Michigan) with 1.77 g U/cm³														
11. WPI	10^{-2}	24	Alloy	0.38	10	136	13.6	99	30	39	2.50(?)	24.0	2.79(?)	3.047 = 3.047
LEU:			U_3Si_2	1.77	18	167	9.3	60	15	30	2.14-2.50	22.5-24.0		
12. OSU	10^{-2}	24	Alloy	0.44	10	140	14.0	108	36	36	2.637	24.0	2.877	3.00 = 3.00
LEU:			U_3Si_2	1.77	18	167	9.3	60	15	30	2.14-2.50	22.5-24.0		
Unique Reactors														
13. M.C.	10^{-7}	1C	Alloy	0.71	18[b]	200	Var.	50	15	2C	Var.	24.0	Var.	3.5 in. O.D.
LEU:			U_3Si_2	3.84		230								
14. RPI	$<10^{-6}$	21	UO_2-SS	1.82	4-11	Var.	28.62	30	5(SS)	20	2.54	21.75	2.77	2.86 = 2.86
		4	UO_2-SS	1.80	6	161.7	27.07	30	5(SS)	20	2.32	21.125	2.55	2.86 = 2.86
LEU: SPERT Pins, 4.8% Enrichment, SS cladding														
19. MURR	10	8	UAl_x	~1.6	24	780	Var.	50	15	20	Var.	24.0	Var.	Pie Shaped
LEU Options Require Feasibility Study														
20. MIT	5	~24	UAl_x	~1.6	15	510	34.0	60	15	30	2.08	22.38	2.53	Rhomboid
LEU Options Require Feasibility Study														
FNR-LEU	2	~30	UAl_x	1.77	18	167	9.3	60	15	30	2.14-2.50	22.5-24.0	2.775	2.94 = 3.25

[b] Cylindrical elements with 6 concentric rings (3 plates each) per element.

Table 1.4

LEU FUEL PROCUREMENT COST ($000) ESTIMATE
BASED ON MINIMUM CHANGES IN CURRENT FUEL ELEMENT GEOMETRY

	Reactor	No. of Elements	Setup Cost ($000)		Manufacturing Cost ($000)		Sub-total	Contract Administration Surcharge (5.8% of B&W)	Procure-ment Package	Total Cost	Cost per Element
			Labor	Materials/ Sublet	Labor	Materials/ Sublet					
	Plate-Type Reactors										
			B&W	B&W	B&W	B&W	B&W	EG&G	EG&G		
1.	GTRR	37	14	41	222	25	302	18	13	333	9.0
2.-3.	UVAR & UVA CAV	40	14	14	258	28	314	18	13	345	8.6
4.-5.	RINSC & Lowell	84	14	17	530	58	619	36	13	668	8.0
6.	UM-Rolla	28	14	14	128	24	180	10	13	203	7.3
7.	Purdue	16	14	14	75	27	130	8	13	151	9.4
8.	Florida	44	14	14	178	61	267	15	13	295	6.7
9.	Washington	26	14	14	111	34	173	10	13	196	7.5
10.	Iowa State	15	14	14	88	11	127	7	13	147	9.8
11.	WPI	30	14	22	172	21	229	13	13	255	8.5
12.	Ohio State	29	14	22	156	32	224	13	13	250	8.6
13.	Manhattan College	16	27	215	141	15	398	23	13	434	27.1
		365	167	401	2059	336	2963	171	143	3277	9.0
14.	RPI	25	(SPERT Pins, 4.8% Enr., SS Clad.)				320	20	13	353	13.6
	Subtotal (Plate-type)	390					3283	191	156	3630	9.3

Table 1.4. (Cont'd.)
TRIGA-Type Reactors

15.	Oregon State	91	Single Rods	602	35		637	7.0
16.	Wisconsin	27	4-Rod and 3-Rod Clusters	715	42		757	28.0
17.	Texas A&M	27	4-Rod and 3-Rod Clusters	696	40		736	27.3
18.	Washington State	30	4-Rod Clusters	786	46		832	27.7
	Subtotal (TRIGA-Type)			2799	163		2962	
	TOTAL			6082	354	136	6592	

---

* Manufacturer to be determined.

Table 1-5
LEU FUEL PROCUREMENT COST ($000) ESTIMATE BASED ON TWO STANDARD FUEL PLATES OR ONE STANDARD FUEL PLATE WITH TWO FISSILE LOADINGS

			Setup Cost ($000)		Manufacturing Cost ($000)			Contract Administration	Procure-		
	Reactor	No. of Elements	Labor	Materials/ Sublet	Labor	Materials/ Sublet	Sub- total	Surcharge (5.8% of B&W)	ment Package	Total Cost	Cost per Element
					Plate-Type Reactors						
			B&W	B&W	B&W	B&W	B&W	EG&G	EG&G		
1.	GTRR	37	14	41	222	25	302	18	13	333	9.0
2.-3.	UVAR & UVA CAV	40	14	14	258	28	314	18	13	345	8.6
4.-5.	RINSC & Lowell	84	14	17	530	58	619	36	13	668	8.0
6.	UM-Rolla	33	7	14	195	24	240	14	13	267	8.1
7.	Purdue	16	7	14	104	27	152	9	13	174	10.9
8.	Florida	44	7	14	231	61	313	18	13	344	7.8
9.	Washington	26	7	14	144	34	199	12	13	224	8.6
10.	Iowa State	15	7	14	119	11	151	9	13	173	11.5
11.	WPI	30	7	14	186	21	228	13	13	254	8.5
12.	Ohio State	29	7	14	167	32	220	13	13	246	8.5
13.	Manhattan College	16	27	215	141	15	398	23	13	436	27.1
		370	118	385	2297	336	3136	183	143	3462	9.4
14.	RPI	25	(SPERT Pins, 4.8% Enr., SS Clad.)				320	20	13	353	13.6
	Subtotal (Plate-Type)	395					3456	203	156	3815	9.7

Table 1.3. (Cont'd.)
TRIGA-Type Reactors

15.	Oregon State	91	Single Rods	602	35		637	7.0
16.	Wisconsin	27	4-Rod and 3-Rod Clusters	715	42		757	28.0
17.	Texas A&M	27	4-Rod and 3-Rod Clusters	696	40		736	27.3
18.	Washington State	30	4-Rod Clusters	786	46		832	27.7
	Subtotal (TRIGA-Type)			2799	163	—	2962	
	TOTAL			6255	366	156	6777	

---

[a] Manufacturer to be determined.

Table 1-6

LICENSING COST ($000) ESTIMATE

Actual licensing costs will depend on the actions and requirements of NRC. A range of costs is estimated based on $8,000 (8K) per ~~man-month~~. The cost of litigation due to possible interventions is not included.

	Reactor	Man-Months	Cost ($000) Range
		Plate-Type Reactors	
1.	GTRR	6 - 12	48 - 96
2.	UVAR	6 - 12	48 - 96
3.	UVA CAV	3 - 9	24 - 72
4.	RINSC	6 - 12	48 - 96
5.	Lowell	3 - 9	24 - 72
6.	UM-Rolla	3 - 9	24 - 72
7.	Purdue	3 - 9	24 - 72
8.	Florida	3 - 9	24 - 72
9.	Washington	3 - 9	24 - 72
10.	Iowa State	3 - 9	24 - 72
11.	WPI	3 - 9	24 - 72
12.	Ohio State	3 - 9	24 - 72
13.	Manhattan College	3 - 9	24 - 72
14.	RPI	9 - 18	72 - 144
	Subtotal (Plate-Type)	57 - 144	456 - 1152
		TRIGA-Type Reactors	
15.	Oregon State	3 - 12	24 - 96
16.	Wisconsin	3 - 12	24 - 96
17.	Texas A&M	3 - 12	24 - 96
18.	Washington State	3 - 12	24 - 96
	Subtotal (TRIGA-Type)	12 - 48	96 - 384
	TOTAL	69 - 192	552 - 1536

Table I-7.
TRANSPORTATION COST ($000) ESTIMATE FOR IRRADIATED AND FRESH HEU FUEL AND FRESH LEU FUEL

	Reactor	No. of HEU Elements Irrad.	Fresh	Preparations	Load HEU Irrad. Elements	Transport HEU Irrad. Elements	Transport HEU Fresh Elements	HEU LLW Disposal	Additional Apportioned Costs	Total
					Plate-Type Reactors					
1.	GTRR	20	24	3.0	1.9	2.6	2.0	1.0	10.8	21.3
2.-3.	UVAR & UVA CAV	88	0	4.2	5.7	8.8	0	3.0	11.0	32.7
4.	RINSC	64	6	3.1	3.8	11.4	1.0	2.0	10.9	32.2
5.	Lowell	38	6	1.8	2.8	6.5	1.0	2.0	10.9	25.0
6.	UM-Rolla	33	0	3.3	2.7	5.1	0	1.0	10.8	22.9
7.	Purdue	16	2	2.1	1.9	4.4	0	1.0	10.8	20.2
8.	Florida	23	5	2.5	1.9	3.1	0	1.0	10.8	19.3
9.	Washington	26	2	2.5	1.9	5.5	0	1.0	10.8	21.7
10.	Iowa State	13	4	2.1	1.9	6.1	0	1.0	10.8	21.9
11.	WPI	26	2	2.5	1.9	6.2	0	1.0	10.8	22.4
12.	Ohio State	29	0	3.3	1.9	4.2	0	1.0	10.8	21.2
13.	Manhattan College	16	0	0.5	0	0	2.0	0	3.0	5.5
14.	RPI	25	0	0.5	0	0	2.0	0	3.0	5.5
	Subtotal (Plate-Type)	417	51	31.4	28.3	63.9	8.0	15.0	125.2	271.8
					TRIGA-Type Reactors					
15.	Oregon State	24	3	9.4	8.8	26.4	1.0	0	10.8	56.4
16.	Wisconsin	24	4	9.4	8.8	37.4	1.0	2.0	10.8	69.4
17.	Texas A&M	24	1	9.4	8.8	40.0	0	2.0	10.8	71.0
18.	Washington State	24	3	9.4	8.8	24.4	1.0	2.0	10.8	56.4
	Subtotal (TRIGA-Type)	96	11	37.6	35.2	128.2	3.0	6.0	43.2	233.2
	TOTALS	513	62	69.0	63.5	192.1	11.0	21.0	168.4	525.0

Table 1-7. (Cont'd.)

[a] Additional Apportioned Costs	
I. Overall Planning and Coordination	25.7
II. Special Handling Equipment	5.0
III. Shipping Fresh LEU Fuel to Reactor	30.0
IV. Contingency	60.0
V. 10% Management Fee	47.7
TOTAL ADDITIONAL APPORTIONED COSTS	168.4

Notes:

Assumed to be shipped with irradiated fuel.

Assumed to be shipped as fresh fuel because of essentially zero burnup.

Shipped as four individual rods per equivalent four-rod cluster.

ADDITIONAL NOTES ON COST COMPONENTS OF TABLE 1-7

Preparations - Coordination of transportation arrangements, cutting plate-type elements, disassembly of TRIGA clusters, disassembly of plate-bundles and reassembly into more compact bundles.

Load Irrad. Elements - Rental of cask handling equipment (crane, forklift, etc.) and manpower to load cask.

Transport Irrad. Elements - All trucking charges including deadhead charges, extra driver and special security charges, unloaded and loaded cask freight charges, and detention charges during cask loading and unloading.

Transport Fresh HEU Elements - Freight and special security charges for shipment of fresh HEU elements to a DOE repository.

HEU LLW Disposal - Packaging and shipping to a DOE repository of low-level waste from cutting of elements and disassembly of TRIGA clusters.

Overall Planning and Coordination - All activities needed to make detailed plans for shipping from each rector site.

Special Handling Equipment - Equipment (hoists, transfer casks, etc.) which will be needed to transfer elements from the reactor pool to the shipping cask.

Shipping LEU Fuel - Freight charges for shipment of fresh LEU fuel from B&W and GA Technologies to reactor site.

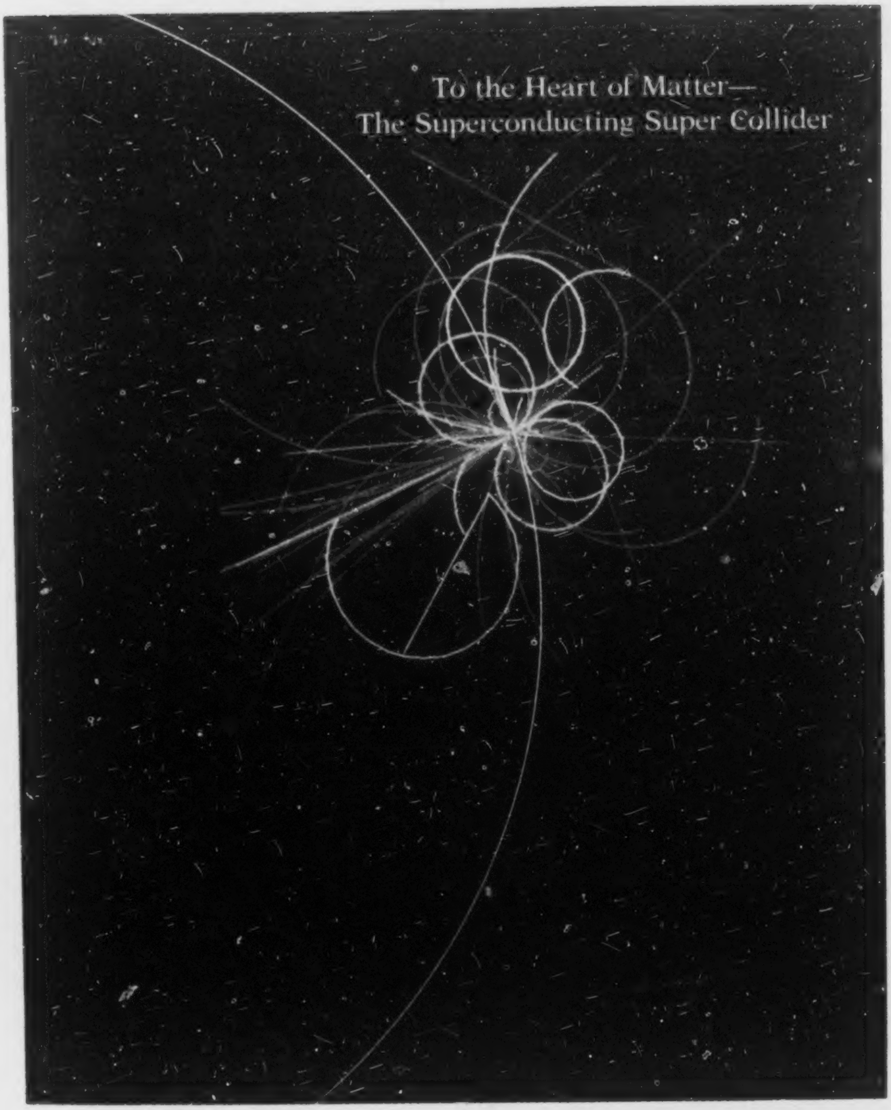
Contingency - Additional deadhead and detention charges and other unanticipated costs.

Table 1-8.

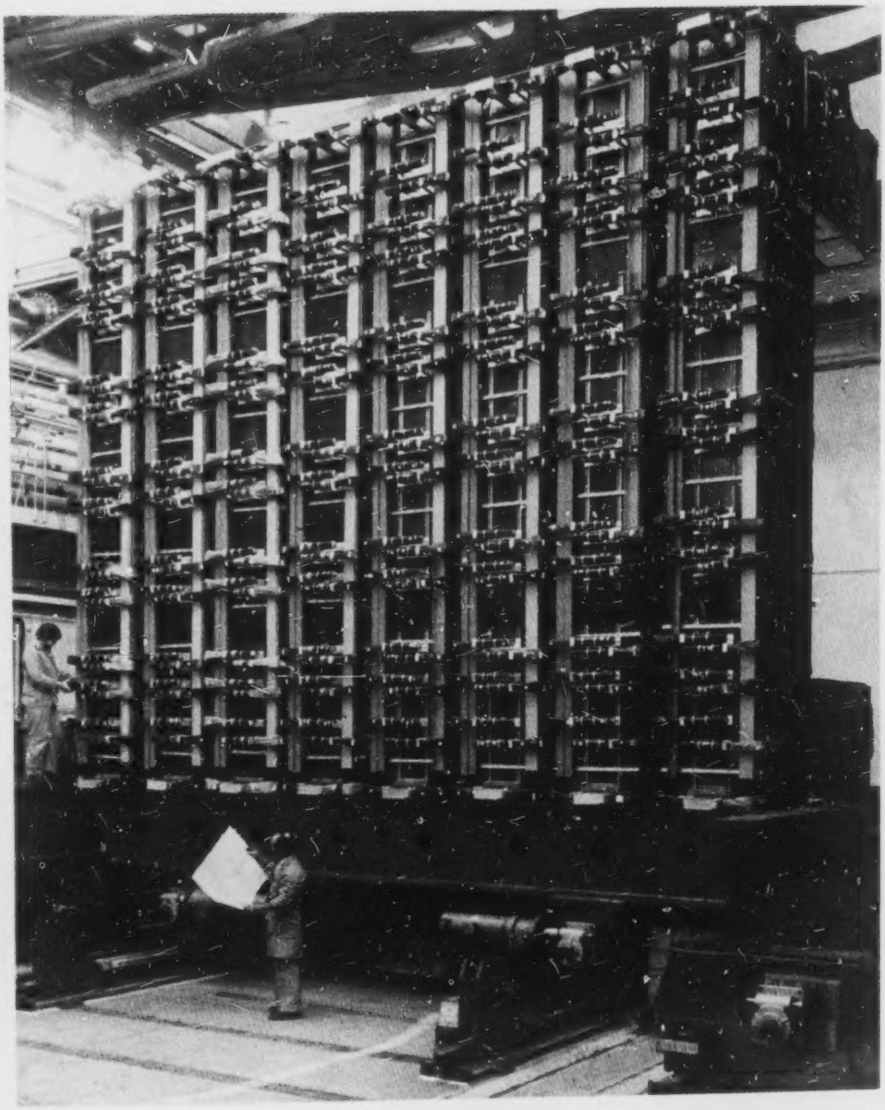
REACTOR STARTUP COST ($000) ESTIMATE

Estimated range of costs to reactor operator to start up the new core with LEU fuel, recalibrate instruments, etc. Based on $8,000 (8K) per man-month.

	Reactor	Man-Months	Cost ($000) Range
		Plate-Type Reactors	
1.	GTRR	1 - 3	8 - 24
2.	UVAR	1 - 3	8 - 24
3.	UVA CAV	1 - 2	8 - 16
4.	RINSC	1 - 3	8 - 24
5.	Lowell	1 - 3	8 - 24
6.	UM-Rolla	1 - 2	8 - 16
7.	Purdue	1 - 2	8 - 16
8.	Florida	1 - 2	8 - 16
9.	Washington	1 - 2	8 - 16
10.	Iowa State	1 - 2	8 - 16
11.	WPI	1 - 2	8 - 16
12.	Ohio State	1 - 2	8 - 16
13.	Manhattan College	1 - 2	8 - 16
14.	RPI	2 - 3	16 - 24
	Subtotal (Plate-Type)	15 - 33	120 - 264
		TRIGA-Type Reactors	
15.	Oregon State	1 - 2	8 - 16
16.	Wisconsin	1 - 2	8 - 16
17.	Texas A&M	1 - 2	8 - 16
18.	Washington State	1 - 2	8 - 16
	Subtotal (TRIGA-Type)	4 - 8	32 - 64
	TOTAL	19 - 41	152 - 328



To the Heart of Matter—The Superconducting Super Collider



To the Heart of Matter—
The Superconducting Super Collider

Universities Research Association
Washington, D.C.

March 1985

Cover: Photograph of a computer-generated simulation of a proton-proton collision at the SSC, with a total energy of 40 TeV. The colors represent different kinds of particles created in the collision. (Courtesy of Fermi National Accelerator Laboratory.)

Opposite: Part of the 2000-ton UA1 detector at the Super Proton Synchrotron collider at CERN, in Geneva. It was used in the discovery of the W and Z bosons in 1983. (Courtesy of CERN.)

Universities Research Association

Member Institutions

- University of Arizona
- Brown University
- California Institute of Technology
- University of California, Berkeley
- University of California, Los Angeles
- University of California, San Diego
- Carnegie-Mellon University
- Case Western Reserve University
- University of Chicago
- University of Colorado
- Columbia University
- Cornell University
- Duke University
- The Florida State University
- Harvard University
- University of Hawaii at Honolulu
- University of Houston
- University of Illinois
- Indiana University
- The Iowa State University
- University of Iowa
- The Johns Hopkins University
- University of Maryland
- Massachusetts Institute of Technology
- Michigan State University
- The University of Michigan
- University of Minnesota
- University of North Carolina
- Northeastern University
- Northwestern University
- University of Notre Dame
- The Ohio State University
- University of Pennsylvania
- Princeton University
- Purdue University
- Rice University
- The University of Rochester
- The Rockefeller University
- Rutgers—The State University
- Stanford University
- State University of New York at Buffalo
- State University of New York at Stony Brook
- Stevens Institute of Technology
- Syracuse University
- The University of Texas at Austin
- University of Toronto
- Tufts University
- Tulane University
- University of Utah
- Vanderbilt University
- University of Virginia
- Virginia Polytechnic Institute and State University
- University of Washington
- Washington University
- University of Wisconsin—Madison
- Yale University

Overview

The universe consists of elementary particles interacting through fundamental forces. All the sciences and all technologies are founded on our knowledge of these phenomena. Furthering this knowledge hinges on the development of ever more powerful scientific instruments with which to investigate otherwise inaccessible domains. With the advent of particle accelerators in this century, spectacular progress has been made. Countless fundamental questions remain unanswered, however.

By overwhelming consensus, the particle physics community in the United States has recommended that the nation's number one priority in this basic field of science be the construction of an accelerator that will extend the high-energy frontier into a realm where fundamental new phenomena are expected. This accelerator is the **Superconducting Super Collider** (SSC), a 20-trillion-electron-volt proton synchrotron. It will provide an unparalleled insight into the world of elementary particles and, indirectly, into events that occurred during the first moments of existence of the universe.

The SSC is designed to answer some of the deepest questions of physics. It may also point the way to one of the most basic goals of physics: the discovery of a correct Grand Unified Theory of fundamental forces. If history is any guide, it will produce discoveries of a totally unexpected nature as well, leading to new directions in scientific inquiry.

The incentive to pursue research of this kind derives not just from the ageless need to expand the limits of our knowledge, but also from the conviction, born of all past experience in science, that doing so will eventually bring great benefits to society. The technological marvels that we take for granted today are the spin-offs from yesterday's basic research.

Qualified scientists from around the world will work at the SSC, thus continuing a long tradition of international cooperation in particle physics. This will also reverse the trend that in recent years has led many outstanding American physicists to seek forefront research opportunities abroad. As a training ground for young physicists at the threshold of their careers, the SSC will play an important role in American higher education. Its challenging demands in both physics research and the applications of high technology will help to prepare many scientists for positions of leadership in academia, industry, and government.

In its use of powerful superconducting magnets, the SSC will both exploit and advance this remarkable new technology, whose great potential for industrial applications has barely been tapped. In other technologies, the rigorous demands of the SSC and its particle detectors will also advance the state of the art. The attendant benefits in many other fields of science and engineering are themselves likely to stimulate future progress in accelerator technology.

Neither the answers to fundamental questions of physics nor their eventual impact on society can be predicted with confidence. But in providing the answers to some of the questions we are now asking—and some that we cannot yet even imagine—the SSC will open a new window on the cosmos, thereby expanding the foundation of knowledge upon which our future will be built.

Introduction

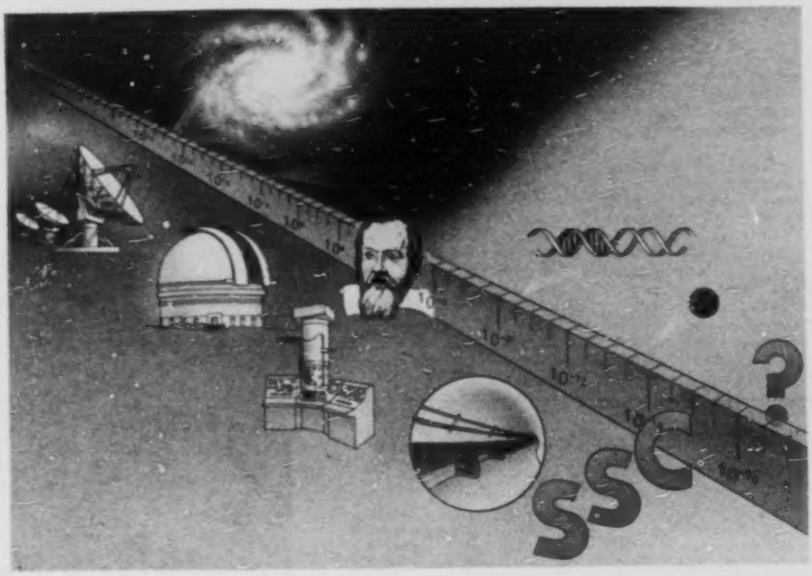
From his central position, man can survey the grandest works of Nature with the astronomer or the minutest works with the physicist.

Sir Arthur S. Eddington

Mankind's curiosity about nature has surely been the dominant force in the development of civilization. Our history has been shaped by the irresistible urge to find out how the world works and how we can use this knowledge to better our lot. Among the most basic questions we have always asked are: What is the ultimate structure of matter? What are the forces through which matter interacts? How did the universe begin? Will it ever end?

These questions—particularly the first two, but increasingly the last two as well—fall within the domain of elementary particle physics, upon which our knowledge of the other sciences ultimately rests. As biology and medicine are founded in chemistry, and chemistry in physics, so all of physics is founded in the study of the elementary particles and the forces that govern their behavior. Although the tree of knowledge will continue to be explored fruitfully at many levels, it is only by uncovering its deepest roots that we can fully comprehend the branches above.

Particle physics is perhaps the most fundamental of the sciences, but astronomy is the oldest. Throughout history, nothing has so stirred our imagination,



scientific and poetic alike, as contemplation of the heavens. Until very recently, it could scarcely have been foreseen that some of the age-old mysteries of astronomy might be solved by looking in the opposite direction: down to the elementary particles, where powerful forces give all matter its form. Yet this is precisely what is now happening. Particle physicists, together with nuclear and atomic physicists, astrophysicists, and cosmologists, are beginning to understand not just what matter *is*, but where it came from, and when, and how.

Finding the answers to such questions is important, because everything else that we want to know more about—space and time, energy and entropy, life and death, the rocks of the earth and the fire of the stars—is deeply connected to them. As our knowledge advances, so must the power and precision of the scientific instruments upon which further advances will critically depend. This brochure is about one such instrument, the *Superconducting Super Collider*, or SSC.

Windows on the Cosmos

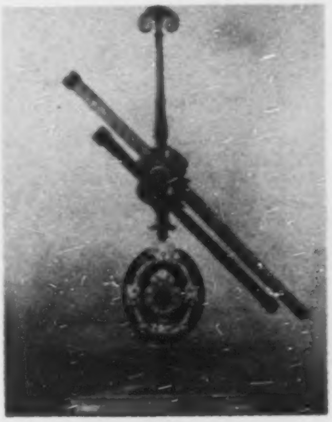
In 1608, a young apprentice optician in The Netherlands stumbled into one of the great milestones of science—indeed, of civilization. While playing with some lenses that were to be made into spectacles, he noticed that looking through them while holding them a certain distance apart made remote objects appear magnified. His master, Hans Lippershey, promptly mounted such lenses in tubes and offered to sell this crude invention, the first telescope, to the Dutch government. Despite the government's efforts to keep the device secret because of its potential value in warfare, the news of it leaked out and soon reached Galileo in Italy.

The rest of this story is well known, though its end is nowhere in sight. Through the boy's good luck and Galileo's creative genius, a universe of unimagined size and splendor blazed into the consciousness of mankind. With wonder and astonishment, we have been looking outward ever since, to the farthest reaches of space and time.

And inward as well, for the telescope, when turned around, became a microscope. (Among the first to experiment with microscopes was Galileo himself.) Yet another universe, one of fantastic variety and subtlety, was suddenly revealed to exist within ourselves and everything around us. The gross features of the everyday world were seen to arise from the forms and functions of objects as remote from our unaided senses as the stars are from our physical grasp. With the ensuing flood of new scientific knowledge, our conception of nature and our place in it was profoundly altered.

To this day, microscopes and telescopes remain among the premier tools for scientific research, although they hardly resemble their primitive ancestors. As the increasing power and variety of these and many other instruments extend our vision ever deeper, their increasing precision—equally vital to scientific progress—enables us to put the most fundamental theories of nature, such as relativity and quantum mechanics, to stringent tests.

Among the most powerful and precise of all modern instruments are particle accelerators—the "ultimate microscopes." Their piercing gaze into the very heart of matter holds the promise of revelations not only about the basic constituents of the universe but also about the creation of the universe itself. Thus our expanding knowledge of the infinitesimal is leading us, almost miraculously, to an understanding of the infinite. After almost four centuries, Galileo's two great windows on the cosmos are merging into one.



Right: Galileo's original telescope, now in the Science Museum of Florence. (Scala/Art Resource.)

Opposite: A "meter stick" for objects in the universe. The four objects shown span the immense range of almost 40 orders of magnitude in size. Opposite each one is a scientific instrument used for examining it. The DNA molecule can be seen with an electron microscope. Examining the proton (which contains three quarks) requires a particle accelerator.

What Is the SSC?

I shall begin by making some experiments before I proceed any further; for it is my intention first to consult experience and then show by reasoning why that experience was bound to turn out as it did. This, in fact, is the true rule by which the student of natural effects must proceed. . . .

Leonardo da Vinci

Imagine two adjacent rings of metal pipe, roughly 100 kilometers in circumference, contained in a circular concrete tunnel several meters below the ground. The pipes themselves are only a few centimeters in diameter. They are under high vacuum and are surrounded by long, powerful electromagnets that are cooled to an ultralow temperature.

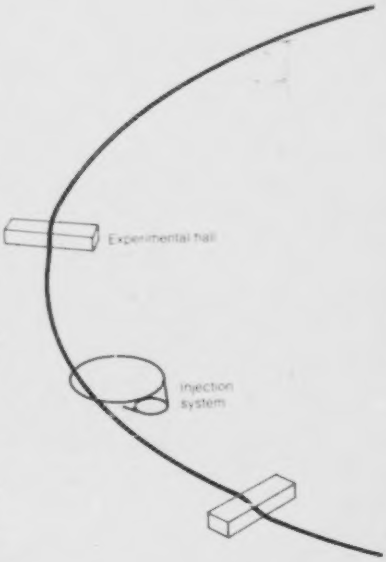
Inside the two pipes are thin beams of protons whirling around the ring in opposite directions at very nearly the speed of light. They have been accelerated to a kinetic energy of 20 TeV (20 trillion electron volts) per proton. This energy, colossal on the scale of subatomic particles, represents a 20,000-fold increase in the effective mass of the particle, as predicted by Einstein's famous equation $E = mc^2$. (A similarly accelerated baseball would have an effective mass of about 3 tons.)

In several experimental halls located around the tunnel, the proton beams intersect each other almost head-on. For the most part, they pass through each other unscathed, but occasionally two protons collide. A few of the clashes are so violent that a considerable portion of the protons' kinetic energy is converted to mass in the form of other particles.

Bursting into existence from within the tiny cataclysm, the shower of subnuclear particles—among which, in rare cases, may be a new and exotic one—flashes outward in all directions. Sophisticated electronic detectors, backed up by large computers, record the particles' trajectories and other properties. Around the world, physicists analyze these records for clues to the ultimate structure of matter and the nature of the forces through which matter interacts.

This is the Superconducting Super Collider, the world's premier particle accelerator, which will boost its proton beams to energies 20 times higher than ever achieved before. It will enable physicists to investigate the elementary constituents of matter with unprecedented precision, in the realm of distances much smaller than the diameter of a proton. In a very real sense, the SSC can be regarded as a microscope of far greater resolving power than any other.

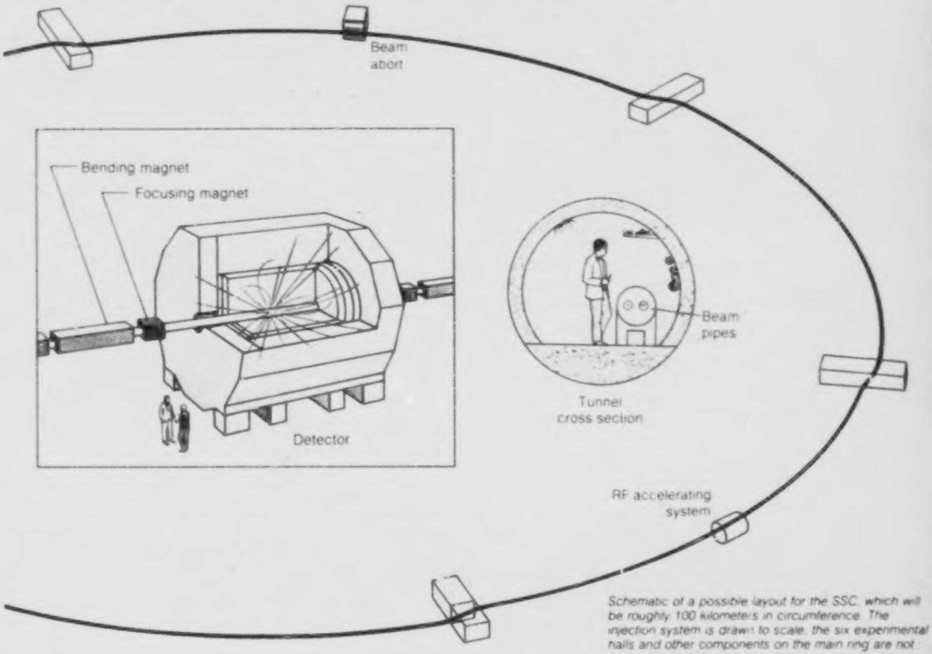
It is a law of nature that the smaller the object to be examined, the higher must be the energy of the beam used for probing it. At the subnuclear level, optical microscopes and even the much more powerful electron microscopes are grossly inadequate for the task. The requisite beam energies can be produced only by large



particle accelerators; at present, both electron and proton machines are used for this purpose. In seeking to enter the realm of multi-TeV energies, however, we are limited by available technology to the use of protons.

The proton is the tiny nucleus of the hydrogen atom. In terms of size, a proton is to a mosquito as a mosquito is to Mercury's orbit around the sun. A 20-TeV proton and a mosquito in flight have comparable energies, but the difference in their *energy densities* (energy per unit volume) is clearly enormous. It is the accelerated proton's great energy density, not its energy per se, that makes it so effective a probe of the tiniest units of matter.

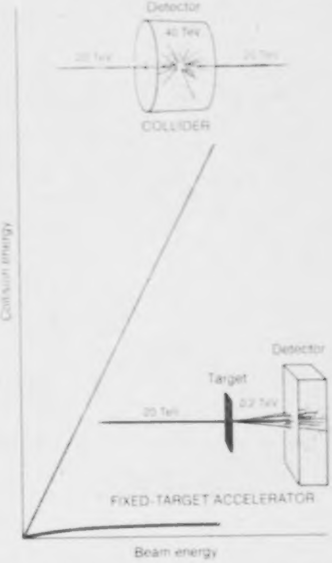
Because protons carry a unit of electric charge, they are affected by static electric and magnetic fields and by electromagnetic radiation, such as radio waves. It is radiofrequency fields, in fact, that are used to accelerate the protons, which are given a slight boost in kinetic energy each time they pass through the field. To build up the huge energies needed for particle



Schematic of a possible layout for the SSC, which will be roughly 100 kilometers in circumference. The injection system is drawn to scale; the six experimental halls and other components on the main ring are not. In the detail of the detector, the beam pipe and its magnets are shown oversize for clarity.

physics experiments requires many passes—millions, typically—through the field, and this is why a circular accelerator is necessary.

The "main ring" of the SSC is the last, and by far the largest, of several linked accelerators through which the protons must pass in order to reach maximum energy. In one example of such a system, the protons begin their journey in a linear accelerator that boosts them to an energy of 1 GeV (1 billion electron volts) before injecting them into a circular booster synchrotron of 70 GeV. From there they enter



The great advantage of a collider is shown in this graph (not to exact scale). Colliding beams of 20 TeV each yield a total useful energy of 40 TeV. A 20-TeV beam on a fixed target yields a useful energy of only 0.2 TeV; the rest is wasted in forward motion of the collision products.

Particle Accelerators

Accelerators are to particle physics (and nuclear physics) as telescopes are to astronomy, and microscopes to biology. All of these instruments reveal and illuminate worlds that would otherwise be forever hidden from our view. They are indispensable for scientific progress.

The earliest accelerators were simple vacuum tubes in which electrons were given a "kick" in energy by the voltage difference between two oppositely charged electrodes. From them evolved the much larger Cockcroft-Walton and Van de Graaff electrostatic accelerators and the powerful, sophisticated linear accelerators (linacs) of today. These machines are used in some of the most advanced areas of scientific and medical research as well as in many practical engineering applications. For particle physics research, however, they suffer the disadvantage of a relatively short flight path available for acceleration, with a consequent limitation on the maximum energy attainable.

The great breakthrough in accelerator technology was Ernest O. Lawrence's invention of the cyclotron in 1930. By providing a long, spiraling flight path for the charged particles, the cyclotron allowed them to undergo many cycles of acceleration and hence to gain unprecedented energy. The culmination of this type of technology is the modern proton synchrotron, with its essentially infinite circular flight path and huge potential for energy gain.

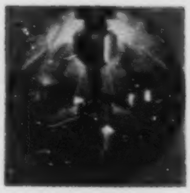
Until two decades ago, all accelerators were fixed-target machines, in which a beam of projectile particles struck a stationary target of some substance of interest. With advancing technology, however, came particle colliders, in which two counter-rotating beams collide head-on in intersection regions located along their path. Several such colliders now exist around the world, and many more are under development or being planned.

In a collider, virtually all of the combined energy of the two particles becomes available for the creation of new matter. The greater the total energy, the more massive the particles that can be created. In a fixed-target machine, by contrast, most of the energy of the one projectile particle is "wasted" as its momentum carries it and the collision products forward. This fundamental advantage of colliders over fixed-target machines becomes proportionally greater (an added bonus) as the beam energy increases.

a larger booster synchrotron of 1 TeV (= 1000 GeV), and finally the main ring itself, for the full 20 TeV.

As many as several thousand powerful electromagnets will be required to keep the proton beams tightly focused and constrained to a circular orbit. They will be *superconducting* magnets, which are expensive to build but inexpensive to operate. The phenomenon of electrical superconductivity (the ability of some materials to maintain perpetual currents without loss) will allow these magnets to produce the large field strengths required by the SSC, without the prohibitive power costs that conventional electromagnets would incur.

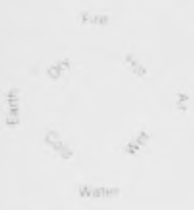
The "proof of principle" of superconducting magnets in high-energy accelerators was brilliantly realized in 1983. After several decades of research and development, these magnets were installed and successfully used in the main ring of the Tevatron, a proton synchrotron at the Fermi National Accelerator Laboratory (Fermilab), near Chicago. The outstanding performance of the Tevatron has paved the way for the SSC and other accelerators of the future. The information these instruments yield will bring us ever closer to an understanding of what the elementary particles really are, and how they came to be.



End view of a radiofrequency quadrupole, a high-precision device used for accelerating and focusing a particle beam. The overall diameter is 32 centimeters. A device of this kind will be used in the first accelerating element (a linear accelerator) of the SSC. (Courtesy of Brookhaven National Laboratory.)

Aerial view of the Fermi National Accelerator Laboratory (Fermilab) at Batavia, Illinois. The main ring of this fixed-target proton synchrotron is 6.3 kilometers in circumference. It is presently being upgraded for operation as a proton-antiproton collider with a total collision energy of 2 TeV. (Courtesy of Fermi National Accelerator Laboratory.)

Elementary Particles: The Eternal Quest



The four Aristotelian elements and their associated qualities.

For more than two thousand years, scientists have been fascinated by the question of the ultimate structure of matter. Aristotle believed that there were just four elements—earth, air, fire, and water—whose myriad combinations accounted for all things. Although this list grew and changed with the passage of time, it was not until the nineteenth century that *atoms* of the chemical elements, of which dozens were known by then, came to be regarded as the fundamental, indivisible components of matter. This belief was shattered in 1897, however, by the discovery of the *electron*, the carrier of electricity and a constituent of all atoms. The electron was, and still is, regarded as an elementary particle.

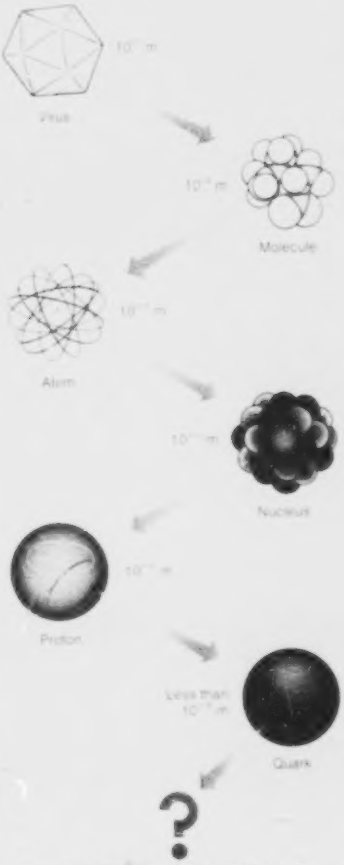
By the early 1930s, other discoveries had been made that revolutionized our view of the material world. Among them were the atomic nucleus and its two constituent particles, protons and neutrons. For many years, both of these were also regarded as elementary—mistakenly, as it turned out. A fourth kind of particle, the *neutrino*, was postulated in 1931, and its existence was eventually proved by experiment. Like electrons, neutrinos are still believed to be elementary particles.

By convention there is color, by convention sweetness, by convention bitterness, but in reality there are atoms and space.

DEMOKRITOS

Meanwhile, the earth was found to be under constant bombardment by *cosmic rays* from outer space. These are extremely energetic particles, mainly protons. Their violent collisions with atomic nuclei in detectors such as photographic films or cloud chambers provided physicists with the first opportunities to study particle interactions at very high energies. Among the created particles discovered in some such events were positrons, which are the *antiparticles* of electrons, carrying a positive charge instead of negative. We now know that for every kind of particle there is a corresponding antiparticle, such as the antiproton for the proton.

During the next few decades, a veritable "particle *zoo*" numbering in the dozens emerged—some from cosmic-ray experi-

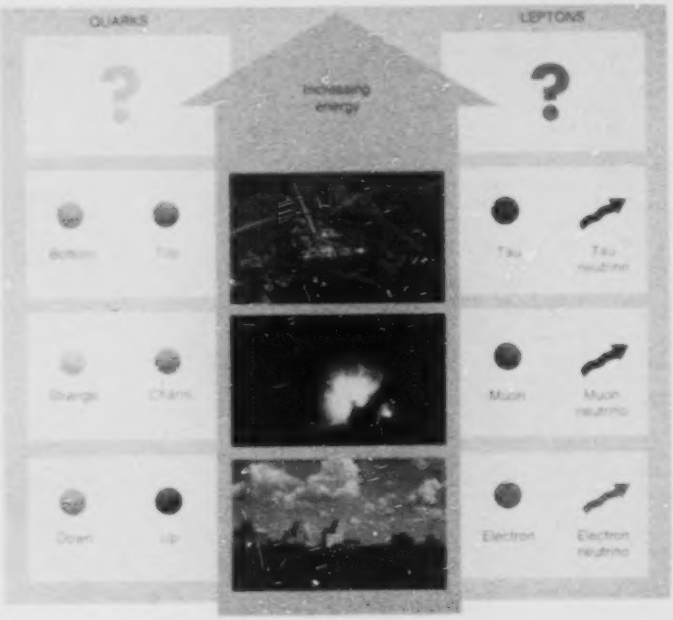


Levels of the structure of matter, beginning with the smallest living thing, a virus. Characteristic dimensions are given in meters. There is as yet no evidence that quarks have any structure, but there is no known reason why they should not have any.

ments but most, since the early 1950s, from accelerators of ever higher energy. Thus the vague term "high-energy physics," to distinguish this subject from its parent, nuclear physics, came into use and still persists. Although today's accelerators still do not attain maximum cosmic-ray energies, they provide the overwhelming advantages of well-defined, controllable experimental conditions and incomparably higher event rates, and thus a good basis for statistical analysis of the results.

Confusion reigned in the particle zoo until the early 1960s, when the idea was proposed that protons, neutrons, and most of the other particles produced in nuclear collisions are not elementary after all, but consist of combinations of two or three smaller particles called *quarks*, each of which carries a fractional unit of electric charge. As radical as this theory was, it soon gained favor because of the elegant way in which it accounted for the properties of all the particles in question. In one master stroke, order was restored, and the number of elementary particles dropped to a relatively small number again.

Demonstrating experimentally that quarks exist turned out to be very difficult. It was eventually recognized that there are fundamental constraints that keep the quarks in bound states and that may make it impossible to observe them



The three known families of quarks and leptons. (The names of the quarks are fanciful and arbitrary.) The lowest-energy families constitute virtually everything in our world. The members of the second families are more likely to be found in the higher-energy domains of astrophysical phenomena; they are routinely produced in particle accelerators and are also seen in cosmic-ray events. The members of the third families existed briefly during the Big Bang and can be produced today in high-energy colliders such as the electron-positron collider at Stanford, for which the 2-mile linear accelerator serves as the injector. Whether additional families can exist is a major unsolved problem of physics. (Photographs from Terraphotographics/BPS, Hale Observatory, and Stanford Linear Accelerator Center, respectively.)

Human subtlety . . . will never devise an invention more beautiful, more simple, or more direct than does nature, because in her inventions nothing is lacking, and nothing is superfluous.

Leonardo da Vinci

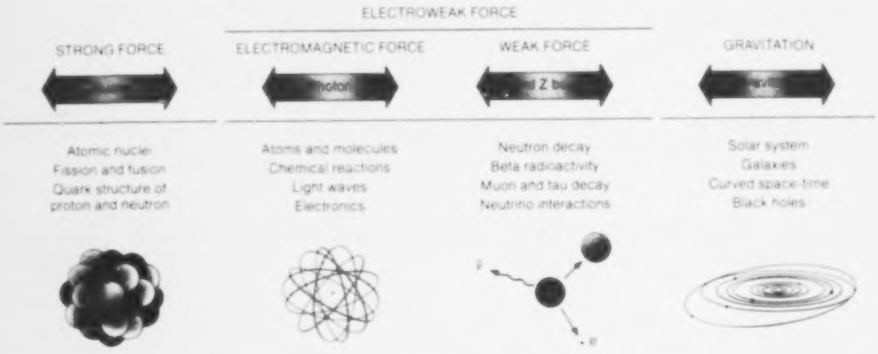
as free particles. Nevertheless, much indirect evidence for their existence has been obtained. We now know of five different quarks and have evidence, as yet inconclusive, for the existence of a sixth. For no apparent reason, they seem to fall into three distinct families of two each.

One of the quarks' characteristics is that they, and all the particles composed of them, experience the strongest force in nature, aptly called the *strong force*. Discovered only a half-century ago, this extremely short-range force is what holds atomic nuclei together despite the electrostatic repulsion between their protons. It also holds quarks together within the confines of protons, neutrons, and all the other "strongly interacting particles."

The strong force has no effect, however, on another major class of elementary particles, the *leptons*. These are the electron, muon, and tau, all of which are negatively charged, and three corresponding neutrinos; the latter are electrically neutral and are believed to have no mass. Despite their unprepossessing nature, neutrinos are of intense interest to physicists because they may hold the key to some of cosmology's deepest secrets. The answers depend critically on the unsolved problem of whether or not neutrinos do have a slight mass after all.

Thus there are six leptons, also occurring in three distinct families of two each. Is this striking parallel between the quark and lepton families significant? We do not know.

Considerably weaker than the strong force is the *electromagnetic force*, which affects all particles having an electric charge or a magnetic moment. Electricity and magnetism, in fact, are the indissoluble components of this force. Their "marriage" came about in the nineteenth century through the ingenious experiments of Michael Faraday and the subsequent brilliant mathematical unification by James Clerk Maxwell. Electromagnetism, a long-range force, is responsible for the structures of atoms and molecules and for almost all chemical, optical, and electronic phenomena. In short, it governs most of


ELECTROWEAK FORCE
STRONG FORCE
ELECTROMAGNETIC FORCE
WEAK FORCE
GRAVITATION
Atomic nuclei
Fission and fusion
Quark structure of proton and neutron
Atoms and molecules
Chemical reactions
Light waves
Electronics
Neutron decay
Beta radioactivity
Muon and tau decay
Neutrino interactions
Solar system
Galaxies
Curved space-time
Black holes
e

Examples of manifestations of the fundamental forces of nature, two of which have been unified mathematically. Double-headed arrows represent the particles that carry the forces. The diagram illustrating the weak force shows a neutron decaying into a proton, an electron, and an antineutrino. Gravitation plays no role in particle physics.

the familiar manifestations of matter and energy in our world.

Third in the hierarchy of forces is the extremely short-range *weak force*, which is much weaker than electromagnetism. It is responsible for all radioactive decay processes and for the decays of many short-lived particles. All quarks and leptons experience the weak force.

Finally, there is the familiar, long-range *gravitational force*, which affects all particles, regardless of their other properties. Its strength is infinitesimal compared with the other forces, so its effects are completely negligible in particle physics. It becomes manifest only at the level of macroscopic objects and is responsible for the large-scale structure of the universe.

It has been a long-standing goal of physicists to simplify this picture—to find deep connections between these apparently very different forces, just as Faraday and Maxwell did for electricity and magnetism. All such attempts failed until a decade ago, when it was shown that the electromagnetic and weak forces can be described in a unified way.

The *electroweak unification* is one of the triumphs of modern physics, both for its great theoretical importance and for its remarkable prediction, confirmed experimentally at CERN (Geneva) in 1983, that three different, very massive *force-carrying bosons* are responsible for the weak force. Called the W^+, W^-, and Z^0 bosons, these objects belong to the class of particles whose role in nature is to mediate the forces between other particles. The rapid exchange of bosons back and forth between other particles *is*, in fact, the force between them. Unlike the three bosons just mentioned, the others have no mass. The electromagnetic force is mediated by massless *photons*, which are the quanta of electromagnetic radiation. The strong force is mediated by massless particles called *gluons* (of which there are eight kinds), and gravitation is believed to be mediated by massless particles called *gravitons*.

Thus, two millennia of scientific inquiry have brought us to the following description of elementary particles and their interactions. There are six kinds of quarks and six kinds of leptons, and for each, a corresponding antiparticle; these 24 particles are the "building-block" constituents of all matter. There are 12 force-carrying bosons for the three forces that are important in particle physics (strong, electromagnetic, and weak), and probably an additional one for gravitation.

Together, the mathematical theories of the strong and electroweak forces are called the *Standard Model* (gravitation is not included). The Standard Model is consistent with all the known facts of particle physics and nuclear physics. Does this mean that it is a complete and satisfactory theory? Far from it!

I have long held an opinion, almost amounting to conviction, in common, I believe, with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin.

Michael Faraday

Whither the Standard Model?

The conviction that nature is fundamentally simple, if only we can penetrate all the layers of apparent complexity, has been a hallmark of scientific thought from the earliest times. The myriad scientific achievements of the past two millennia notwithstanding, we still hold to the ideals of simplicity, symmetry, and harmony embodied in the philosophy of the ancient Greeks. Science is still very much a search for beauty and elegance in the forms and functions of natural systems.

Seen in this light, the Standard Model is unquestionably a scientific masterpiece, *A theory is more impressive the greater the simplicity of its premises, the more diverse the things it relates, and the more extended its area of applicability.*

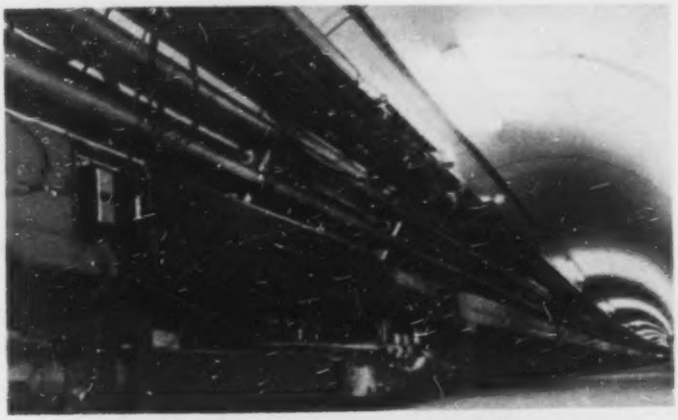
ALBERT EINSTEIN

embodying in its conceptual framework the integration of special relativity and quantum mechanics, the two great cornerstones of modern theoretical physics. Nonetheless, it is an unfinished masterpiece. Although it accommodates all the known facts within its domain, it cannot predict (i.e., cannot really explain) some of the more important ones. It does not predict, for example, how many families of quarks and leptons there should be, nor even why such families should exist at all. In this regard, it is "open-ended."

This situation is a bit unnerving. The possibility of there being even more quarks and leptons than the considerable, and unexplained, number already known to us suggests that they may not be elementary after all. Indeed, several imaginative theories have recently been proposed to explore the possibility of new levels of structure.

Another flaw in the Standard Model is its failure to explain the violations of certain symmetry principles, such as parity, that are believed to underlie the basic laws governing particle interactions. These violations must be built into the Standard Model arbitrarily.

On the other hand, the Standard Model accurately predicts many subtle and complex features of particle physics, and this gives us great confidence that it is fundamentally correct. Its most intriguing prediction concerns another kind of symmetry: that which is embodied in the electroweak unification. For the electromagnetic and weak forces actually to have a common origin implies a deep connection between them in a domain far beyond ordinary experience. According to the Standard Model, this connection becomes manifest only at very high energies or very short distances. In these domains,



The tunnel of the main ring at Fermilab, showing two strings of electromagnets, which surround the beam pipes. The upper string is the older ring of conventional magnets, whose proton beam is currently used as an injector for the new string (below) of superconducting magnets. These guide the beam for what is now called the Tevatron, the world's most powerful fixed-target accelerator. (Courtesy of Fermi National Accelerator Laboratory.)

the symmetry exists and the forces appear the same; at lower energies or larger distances, the symmetry is "broken," and they appear different.

But how does a symmetry break? There must be a particular mechanism, and the Standard Model predicts that this mechanism relies on the existence of a massive particle called the *Higgs boson*. It says little, however, about the mass of this particle, except that it cannot be more than about 1 TeV, or 1000 times the mass of a proton.

To create such a massive particle out of a vacuum would require that an enormous amount of energy be concentrated in a tiny volume of space. This is precisely what the SSC is designed to do. A 20-TeV-on-20-TeV collision of protons will deposit 40 TeV within roughly the volume of a proton. This would seem like 40 times more energy than is needed. On the scale of elementary particles, however, a proton is a rather large, diffuse object made up of a number of quarks and gluons that share the total energy. The proton's energy *density* is much less than that of a pointlike particle with the same energy. The trick, then, is simply to give the protons an excess of energy sufficient to ensure that two of their constituent quarks or gluons will collide with an energy of at least 1 TeV. This is why the SSC is designed as a 20-TeV proton collider.

But can we be sure that the Higgs boson must exist? No! All that is certain is that new phenomena must occur at a mass (energy) scale of about 1 TeV or less. This is because the Standard Model leads to logical inconsistencies in this regime. The Higgs boson is just one way to resolve the inconsistencies. Whether nature actually chose this particular mechanism can only be discovered by experiment.

Finding the Higgs boson or resolving the difficulties with the Standard Model in some other way will be a major breakthrough in physics, but by no means the only one that can be expected from the SSC. At all previous accelerators, some of the most significant discoveries have been totally unexpected. At the SSC, a wealth of new information about the elementary particles and about the behavior of the strong and electroweak forces at extremely short distances is sure to be found. Exactly where this knowledge will lead us is impossible to say, but it could point in many different directions. One of these is likely to be backward in time, toward the creation of the universe. The next section explains how this is possible

Questions . . .

Why are there three families of quarks and three families of leptons? Are there more that have not yet been observed? Why are muons, and perhaps tau leptons, exactly like electrons except for their different masses—or is there some other, subtle difference that has hitherto escaped detection? Do neutrinos have any mass? If so, are they responsible for the "dark matter" of the universe? Do they "oscillate," i.e., change from one kind to another during their long flights through space? Why is parity violated in the weak interaction? Do protons ever decay? Why is there so little antimatter in the universe?

Particle physics today is faced with many questions such as these. Some are quite specific, some very general. The key to scientific progress is knowing which questions are the most important ones to ask. Finding the answers is never a foregone conclusion, of course, nor do the answers, if they are found, necessarily come from the expected quarter. The theories and experiments that we aim at specific questions sometimes provide answers to others that had seemed unrelated. Often they provide important clues that steer further research in new directions, toward questions that had never been asked before.

The SSC will probe a new regime of extremely high energies and massive particles—a *terra incognita* whose like may exist only in violent astrophysical processes from which we are separated by vast reaches of space and time. We could try to predict what will be found there, but we would be wrong as often as not. All that we can be sure of is that a unique new light will be cast on many of our questions, and that our pursuit of their answers will have far-reaching consequences for the science and technology of the future.

Why do the elementary particles have the masses that they do? Why are some particles electrically charged and others neutral? Why do only quarks have fractional units of charge? Why are some of the force-carrying bosons massive and others massless? Why are there eight nearly identical carriers of the strong force and four extremely different carriers of the electroweak force? Can there be a free quark? Can the strong and electroweak forces be unified? Do magnetic monopoles exist? The questions go on and on.

The Cosmic Connection

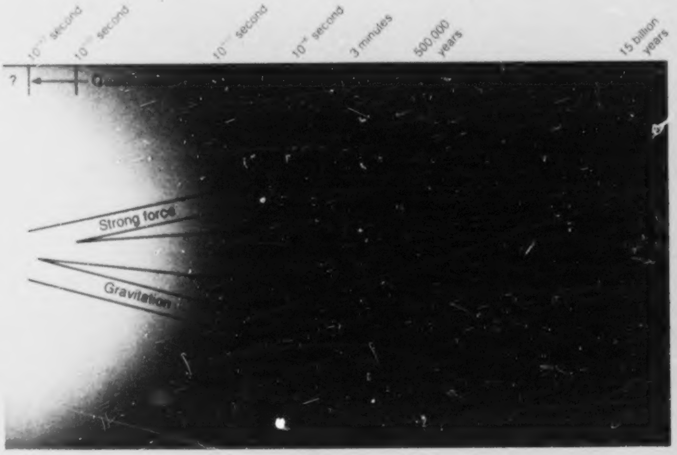
For the road to a knowledge of the stars leads through the atom; and important knowledge of the atom has been revealed through the stars.
Sir Arthur S. Eddington

At the moment of conception, our hereditary destiny is determined, instantly and irrevocably. Our lives are then shaped by the complex interactions of countless factors in our environment, but everything we become and everything we do is related to the patterns established at that original moment.

It was the same with the universe (except, of course, that the universe is its own environment). This is the conclusion drawn from many scientific discoveries made during the last few decades. We now believe that everything that has ever been, or will ever be, derives from what happened at a single moment of creation—the titanic explosion called the *Big Bang*. Cosmology, the study of the structure and evolution of the universe, has been remarkably successful in reconstructing cosmic history back to about one microsecond after the Big Bang, based on our cumulative knowledge of astronomy and many branches of physics.

It was particle physics, however, that reigned supreme during that first dazzling microsecond, when virtually everything of consequence for the fate of the universe took place. In a flash, a subtle chain of events unfolded that established what we, 15 billion years later, observe to be the elementary particles, the fundamental forces, and the laws of nature. The symmetries—and asymmetries—that now underlie everything from the interactions among quarks and leptons to the distribution of galaxies in space were "frozen" into a kind of genetic blueprint for the universe.

To understand how this blueprint was drawn, we must therefore combine our knowledge of particle physics with that of cosmological theory. Considerable progress has already been made, and the relevant course of events can be deduced back to the unimaginably early time of 10^{-43} second. (Compared to this, a microsecond is an eternity.) Still, many mysteries re-



A brief history of the universe from the Big Bang to the present. The four forces became distinguishable by symmetry breakings during the first microsecond. At the end of this period, all the quarks combined to form hadrons (protons, neutrons, and many other kinds of strongly interacting particles), but the leptons have remained as individually observable elementary particles to this day.

main unsolved. Among the most important of these is that of the "dark matter" of the universe.

Cosmological evidence indicates the existence of vast amounts of matter that we have never seen but whose presence can be inferred from its gravitational effects on objects that we *can* see. This dark matter (not black holes, which are a separate issue) may exist in the form of aggregates of massive, stable particles that were produced early in the evolution of the universe. Perhaps the best chance of discovering whether such particles do exist is to recreate on earth, as nearly as possible, the conditions under which they may have been formed. This requires the highest possible energies that can be produced in particle accelerators—it requires the SSC.

The discovery of supermassive particles, whatever they may turn out to be, might help to resolve the dark matter problem. It might also point the way to one of the principal goals of particle physics: to unify the strong and electroweak forces mathematically in what is called a *Grand Unified Theory* of the fundamental interactions. (Incorporating gravitation into such a theory is an additional, more formidable task.)

Paradoxically, a plethora of such theories has already been formulated, but as yet it does not appear that any of them is absolutely correct. These theories deal with the domain of stupendous energies, far beyond the direct reach of the SSC or any other presently conceivable accelerator. Some of them, however, make predictions that lead to observable consequences (such as proton decay), which can, in principle, provide experimental tests of their validity. It is conceivable that discoveries at the SSC could provide indirect evidence that would guide our quest for the correct theory.

Finding *the* Grand Unified Theory, if it exists, would be a major advance in cosmology as well as in particle physics, because it was early during the first micro-

The Big Bang

In the first microsecond there was only particle physics. No atoms, nuclei, or even protons or neutrons could have existed in the fearsome heat—just elementary particles, interacting through fundamental forces.

When the universe was all of 10^{-43} second old, symmetry was broken as the gravitational force apparently became decoupled from the unified strong, electromagnetic, and weak forces. All that existed—a dense, blazing "soup" of quarks, leptons, and bosons (including, perhaps, the Higgs boson)—was compressed into a microscopic volume of space. The temperature was prodigious: about 10^{16} TeV, or 250 trillion times the collision energy of the SSC.

As the universe began to explode, it cooled rapidly; by 10^{-35} second, the temperature was down to about 10^{12} TeV. Here the strong force "froze" out. Symmetry was broken again, and the electroweak force split off and became a separate phenomenon. The quarks continued to be dominated by the strong force (although they interacted electroweakly also), but the leptons were suddenly free of the strong force and interacted *only* electroweakly.

Did the symmetry break smoothly and uniformly? Perhaps not, according to some Grand Unified Theories. Imagine a pond freezing over in winter. It does not happen instantly, with a sheet of ice suddenly appearing over the entire surface. Instead, patches of ice appear randomly and begin to expand. When they have grown together, in a kind of irregular tilework, the result is a crystal structure full of large-scale defects.

In a somewhat analogous manner, the freezing of the strong force may have occurred irregularly, and this might provide the answer to the baffling problem of galaxy formation, which began about 500,000 years later. Galaxies could only have formed, it is believed, if a fluctuation in the distribution of mass was generated at some time during the early expansion of the universe. According to some recent ideas, this could have occurred at the time of the strong-electroweak symmetry breaking.

Much later, at about 10^{-10} second, the universe had cooled to about 100 GeV (0.1 TeV), an energy that is well within the reach of our accelerators. Here the electroweak symmetry broke: the electromagnetic and weak forces became separate, as they have been ever since. At about 10^{-6} second (one microsecond), the quarks began to coalesce into protons, neutrons, and the many other composite particles that we see in the laboratory today. This process was finished in a few microseconds.

As amazing as it seems, nothing truly fundamental has ever happened since then. The actors in the drama of cosmic evolution were all in place, with their lines memorized. For 15 billion years they have played their appointed roles, which we have just begun to fathom.

second that the forces known today are believed to have come into being, through a series of symmetry breakings as the nascent universe expanded and cooled. A deeper knowledge of the primordial symmetry between the strong and electroweak forces would help us understand how and when these forces became separate.

As a kind of "chronoscope" of the early universe, the SSC would tighten our intellectual grasp of events whose existence could not have been imagined when particle accelerators were invented and whose realm had until recently been the exclusive province of philosophers. That we are even capable of using scientific instruments to probe this ultimate mystery from our remote and insignificant place in the universe is itself wondrous to contemplate.

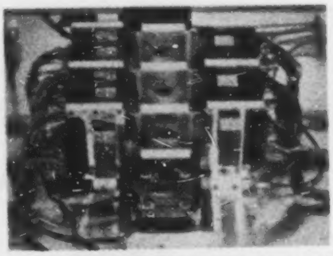
The Crab Nebula is the relic of a supernova explosion whose light was first seen on earth on July 4, 1054. At the core of this vast cloud of glowing gas is the remnant of the star whose violent death produced it: a pulsar, or rapidly rotating neutron star. Terrestrial particle accelerators can provide much information about astrophysical objects. (Lick Observatory.)

Toward New Dimensions

We know from experiments at existing accelerators that the diameter of a proton or neutron is about 10^{-15} meter, or 100,000 times smaller than a typical atom. Quarks and leptons are called pointlike particles, which is merely our way of saying that they are smaller than anything we are presently able to measure—smaller than about 10^{-18} meter, or one-thousandth the diameter of the proton. To open a clear window to such incredibly tiny particles will require a probe in the energy range of a few TeV, comparable to that required to produce the hypothetical Higgs boson.

We saw earlier why a 20-TeV-on-20-TeV proton collider is required to produce quark collisions of a few TeV, the energy at which a new world of physical phenomena is expected to be revealed: it is because of the protons' composite structure and relatively low energy density. We need to make the quarks within the protons collide with sufficient energy to reveal new phenomena and any possible quark substructure. These observations will be quite indirect, of course. We can only infer the information from data that can be measured directly, such as the angles through which the protons and the particles created in the collision are scattered.

To measure these angles, as well as other relevant parameters, such as the masses, charge states, and lifetimes of the created particles, will require detectors of unprecedented capability. A basic feature of most particle detectors is a large volume containing a strong magnetic field surrounding the interaction region. As the particles fly through the field toward a variety of electronic and optical devices that are designed to record their properties, the charged ones are bent into curved paths that depend on their velocity, mass, and charge state. Thus the direction and degree of curvature of a given path provide clues to the particle's identity. The neutral particles, being unaffected by the magnetic field, fly straight through.



Not all particle detectors are huge. This one consists of three silicon chips, about 1 centimeter square, surrounded by arrays of signal amplifiers. The chips actually consist of fine grids of strips, each acting as a separate detector. This permits very high spatial resolution of the trajectories of particles coming through the device. (Courtesy of Brookhaven National Laboratory.)

Because the number of created particles per event may be very large—perhaps hundreds in the SSC—the most sophisticated detectors are segmented into thousands of individual detector modules, for adequate spatial resolution of the showers of particles. Each such module may be a complex device in its own right, consisting of mechanical, optical, and electronic components of high precision and sensitivity. Each may require its own small, dedicated computer to process the torrent of data pouring from it. These computers are linked in a parallel-processing network governed by mainframe computers, which synthesize their output and process it according to elaborate software designed for the experiment in question.

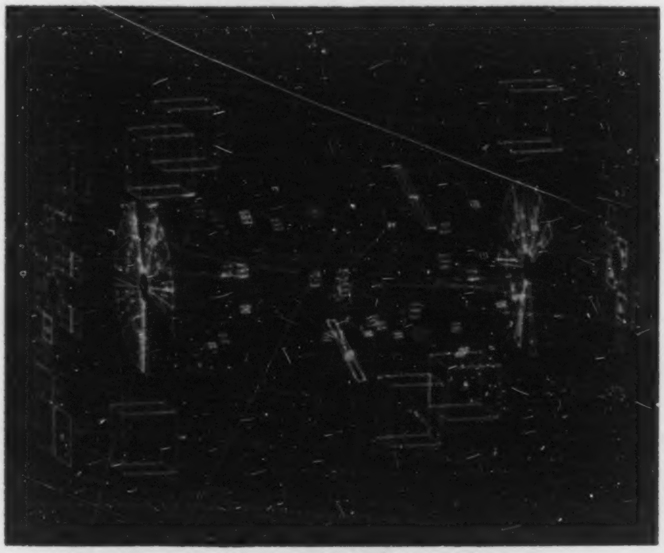
Although the information gained from a single event can provide important clues about new phenomena, a statistical analysis of great masses of information from many similar events is usually needed to interpret the data properly. This requires a very high event rate, especially since most events are of little interest and are quickly rejected by the computers. An event rate high enough to allow an experiment to be completed in a reasonable

Facts which at first seem improbable will, even on scant explanation, drop the cloak which has hidden them and stand forth in naked and simple beauty.

GALILEO

time (a year or so) can only come from an accelerator of high *luminosity*, i.e., one with a large number of collisions per second. The SSC is planned as a high-luminosity collider to allow the detailed study of particle physics in the energy regime of a few TeV. High luminosity, however, imposes stringent requirements on the detectors. They must be able to record complex events producing large numbers of particles, with great precision and in a fraction of a second.

Although none of the technologies described above is fundamentally new, the SSC will push many of them to their outer limits. Their collective realization in the form of the SSC will set new standards for both accelerator and detector design and performance. By using such an instrument to probe the unknown dimensions of extremely high energies and short distances, both the strengths and weaknesses of the Standard Model can be tested more rigorously than ever before. Like all theories of nature before it, it will either be adapted to encompass our new knowledge or be replaced by something better.



Computer-graphic reconstruction of one of the initial Z^0 events observed at the Super Proton Synchrotron at CERN in 1983. The detector used was the UA1, which is shown on the inside front cover. (Courtesy of CERN and Harvard University.)

A Matter of Scale

Although bigger is not always better (witness the microelectronics revolution), there is often no alternative. In particle physics, as a rule, higher energies require larger accelerators. The limitation on the maximum energy achievable with linear accelerators is the practical one of length, based on technologically feasible power sources. To accelerate protons to 20 TeV in one pass down the pipe would require a machine over 1000 kilometers long!

Hence we must use a circular synchrotron, in which the energy builds up gradually over millions of cycles of the beam. Here the size is tractable, but it too has a lower limit. The higher the energy of a particle beam, the more "rigid" it becomes, i.e., the harder it is to bend it along a curved path. The minimum circumference of the accelerator ring is therefore determined by the maximum strength of the electromagnets used for the bending.

The strongest magnets that can be built for the SSC are superconducting magnets. Several possible designs, differing substantially in configuration and in the technical requirements for their construction, are presently under consideration. Significantly, they also differ in maximum field strength and therefore in the size of the main ring that would be required. To bend a 20-TeV proton beam, which is extremely rigid, the circumference of the main ring will have to be in the neighborhood of 100 kilometers.

The choice would seem obvious: use the strongest possible magnets and thus the smallest, least expensive ring. But there is a trade-off, as always: the strongest magnets will be more difficult and expensive to build. When this and many other technical and economic considerations are taken into account, the cost of the basic accelerator is found to be relatively independent of the magnet design chosen.

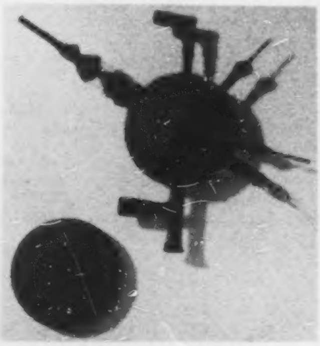
A significant part of the total effort will go toward the superconducting magnets (both the bending and focusing types), whose design, construction, and testing

Aerial view of CERN in Geneva, showing the location of the Super Proton Synchrotron, a proton-antiproton collider with a total collision energy of 640 GeV. It is the world's most powerful collider. The main ring, which is 7 kilometers in circumference, is buried underground. The land above it is undisturbed and retains its traditional use for farming. (Courtesy of CERN.)

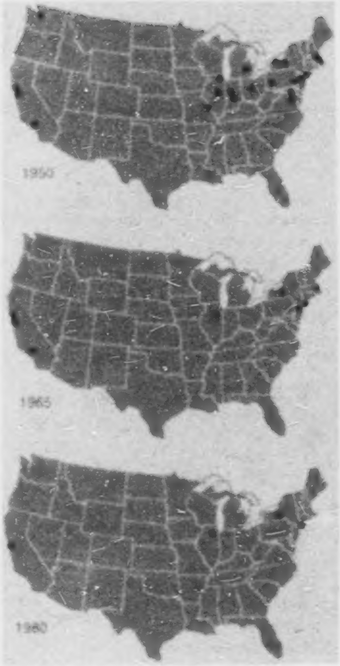
will require advanced technologies and precision engineering of the highest order. In addition to the magnets, other advanced systems for the SSC will include the radiofrequency acceleration cavities, cryogenic facilities, particle detectors, supercomputers, and laboratory equipment. All of these will have to be the state of the art in high technology.

The conventional facilities, by contrast, will not require significant engineering innovation so much as a scaling up of existing methods. Constructing the tunnel and experimental halls, as well as providing the requisite infrastructure of utilities, transportation, housing, laboratories, offices, shops, maintenance, etc., will be large in scope but straightforward in principle.

Lawrence's first working cyclotron was five inches in diameter, a mere toy compared with the mighty accelerators of today. The energy of these instruments has grown tremendously, from a few hundred thousand electron volts to the projected 20 trillion of the SSC—a factor of about



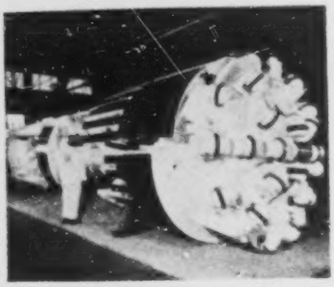
The first operating cyclotron (with the cover removed) invented by Ernest O. Lawrence in 1930. It is about 5 inches in diameter. With it, he accelerated protons to an energy of 80,000 electron volts. (Courtesy of Lawrence Berkeley Laboratory.)



Synopsis of a trend in particle accelerators. As the accelerators, represented by dots on the maps, have evolved to higher energies, their increasing size and cost have forced particle physics research to become ever more concentrated at a few large facilities.

100 million. Naturally, the costs have risen also, but by much less—a factor of about 1 million. Thus the cost per electron volt has declined substantially, owing in large measure to the technological innovations of the past half-century.

As accelerators have grown, their numbers have necessarily decreased. The sheer scale of operation of the highest-energy machines has forced them out of most universities, which had originally been their sole proprietors. In the United States, they are now found mainly at the large national laboratories, where they serve physicists from around the country and around the world. One can no longer contemplate their further development except in this light.



A tunnel-boring machine of the kind that might be used to bore portions of the SSC tunnel, several meters below the surface. A similar machine used for boring the 7-kilometer tunnel at CERN averaged 14 meters per day. (Courtesy of The Robbins Company.)

SSC and the Environment

Despite its great size, the SSC will have little impact on its environment. The main ring and its injector complex will be buried several meters below ground. Few traces of its existence will be seen at the surface when the job is complete. The 8-foot-diameter tunnel will probably be excavated by a combination of cut-and-fill methods and tunnel-boring machines. Very likely it will follow gentle contours of the land, since the beams can be bent up or down slightly as well as sideways.

Six experimental halls, spaced about 15 kilometers apart on the average, are planned for the main ring. Additional structures, such as power supplies, refrigeration units, and access shafts, will also be relatively few and far between. The vast majority of the area enclosed by the ring will be completely untouched. Near the injector complex will be the central laboratory facilities with their associated office and shop buildings, assembly and staging areas, etc. These will be arranged in the manner of a small college campus. Up to 3000 people—permanent staff and visiting scientists—will be employed in what will amount to a small village.

But what about radiation? For the few million years of our existence we have been constantly exposed to radiation from natural sources such as cosmic rays and radioactive isotopes in the ground and in building materials. No new facility should add more than a tiny amount to this natural background.

The SSC will be constructed to meet this requirement, even in the event of an accidental loss of the beam—which would be extremely rare—at some point in the tunnel. The shielding provided by the earth cover above the tunnel will restrict the radiation penetrating to the surface to negligible levels even in the immediate vicinity of the beam loss. In normal operation, there will be no stray radiation whatever, except in the interaction regions. Here, almost all of it will be absorbed by the detectors; very little will reach the tunnel walls, much less penetrate to the surface.

Throughout the facility, stringent industrial safety standards will be maintained. Extensive, continuous radiation monitoring, both inside and outside the tunnel, will assure the protection of SSC personnel and the local population alike. Above ground, access to the vicinities of the experimental halls will be controlled at all times. The outstanding safety record of accelerator operations worldwide will be maintained at the SSC.

Evolution of the SSC Concept

The SSC is the logical consequence of its predecessors. With the rapid advances that have been made in both particle physics and accelerator technology during the past half-century, the evolution of machines of ever higher energy and luminosity has been inexorable. It has epitomized mankind's ambition always to expand the limits of scientific knowledge and technological capability—to achieve not only what is clearly possible but also what at first appears impossible. Much of the progress of civilization has sprung from this "technological imperative."

The imperative for the SSC comes from the strong conviction within the particle physics community that the next milestones in the development of this field will be found in the energy regime of about 1 TeV in quark-quark collisions. The experimental and theoretical advances of recent years have pointed clearly to this view, and the hopes for its realization have been fostered by substantial recent progress in the technologies of superconducting magnets and colliding beams.

The SSC concept was first studied in some depth in the summer of 1982, at a workshop organized by the American Physical Society's Division of Particles and Fields. A subsequent workshop, in the spring of 1983, concluded that there are no fundamental obstacles, in terms of accelerator technology, to the successful construction and operation of such a collider. By this time, an unprecedented unanimity of opinion in favor of the SSC concept had grown within the particle physics community. This opinion was only reinforced by the announcements, in the first half of 1983, of the discoveries of the W^+ and W^- bosons, and then the Z^0 boson, at CERN. (The 1984 Nobel Prize in Physics was awarded for this work.)

All of these considerations led to the conviction that building the SSC should be the number one priority for particle physics in the United States. In July, 1983, the U.S. Department of Energy's High Energy Physics Advisory Panel unanimously endorsed this position; it was underscored by the simultaneous recommendation that two other, less powerful accelerator facilities—one proposed by Fermilab, the other already underway at Brookhaven National Laboratory—should not be constructed.

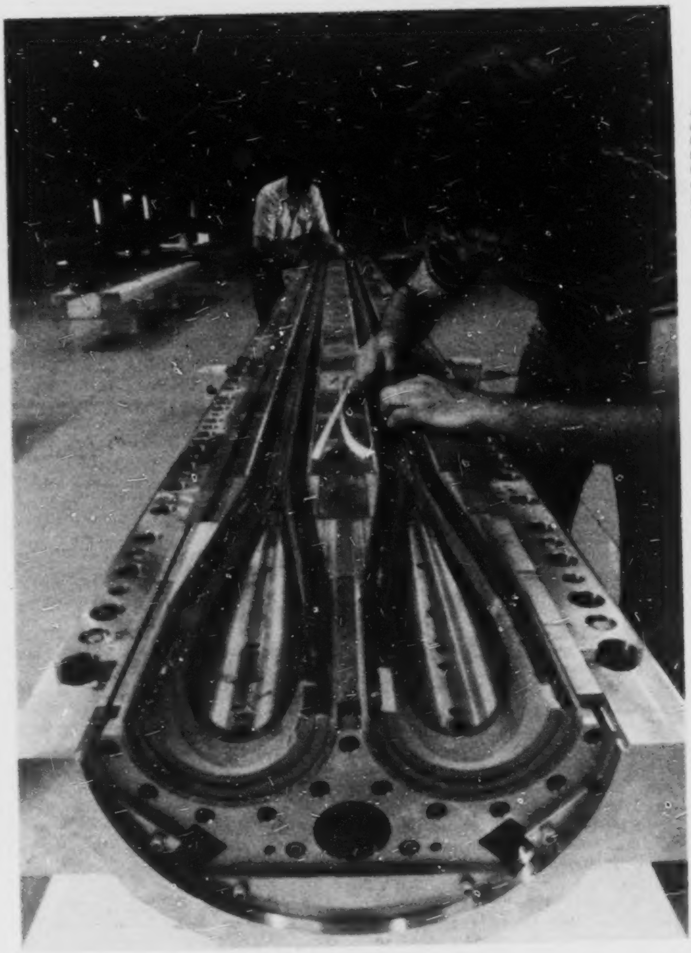
The Department of Energy responded positively. With Congressional approval, funds were quickly reallocated to allow research and development on the new accelerator, principally its superconducting magnets, to begin. R&D programs were established at Brookhaven, Fermilab, the Lawrence Berkeley Laboratory, and the Texas Accelerator Center with the goal of designing magnets that are optimized for performance and reliability while minimizing the cost.

During the first quarter of 1984, a Reference Designs Study Group, with about 160 participants from all major particle physics centers in the United States, convened at the Lawrence Berkeley Laboratory. Its purpose was to review in detail the technical and economic feasibility of various options for creating the SSC facility. The study was based on three superconducting magnet designs, each emphasizing a different configuration and different magnetic field strength. Some of the relevant parameters associated with these designs are shown in the accompanying table.

Parameters Associated with
Three Possible Designs for Bending Magnets

	A	B	C
Peak magnetic field (teslas)	6.5	5.0	3.0
Length of magnet (meters)	16.6	11.2	139.5
Number of magnets	3870	14,880	990
Main-ring circumference (kilometers)	90	113	164.4

It was concluded that the accelerator can be built for approximately $3 billion (in 1984 dollars) and that there are no major technical obstacles to be overcome



A dual-beam and superconducting SSC model magnet in the assembly stage. Its operation requires cooling with liquid helium to a temperature a few degrees above absolute zero. (Courtesy of Brookhaven National Laboratory.)

A dual beam-line superconducting SSC model magnet of a different design. The beam pipe itself can be seen. (Courtesy of Texas Accelerator Center.)

in fulfilling the requirements for either the special or conventional facilities. During the same period, numerous workshops were held on various issues concerning the physics and accelerator technology of the SSC. These culminated in June in a three-week meeting of the Division of Particles and Fields attended by over 200 physicists, including many new Ph.D.'s and many from Canada, Western Europe, and Japan.

Also during the first half of 1984, the management structure for the SSC's R&D effort was established. A Board of Overseers was appointed to hold primary fiduciary responsibility for the project. The Universities Research Association, a consortium of 56 leading research universities, agreed to act as the parent organization of this Board, thus emphasizing the national scope of the SSC effort. The Board appointed Professor Maury Tigner of Cornell University as the Director of the Central Design Group, whose responsibility is to coordinate the R&D activities. The Lawrence Berkeley Laboratory was selected as the host site for this group, with the understanding that the R&D will continue to be carried out at all the institutions mentioned above in connection with the magnet designs.

Formal approval for the first year of this preconstruction R&D effort was granted by the Department of Energy in August, 1984. The first milestone in the current schedule is the completion, in April, 1985, of a document outlining the physical, technical, and demographic requirements for the site of the SSC. The procedures for conducting the search for a suitable site have already been announced by the Department of Energy's Office of Energy Research, in order to ensure an orderly process with fair treatment of all interested parties.

Qualified proposals will be reviewed by a panel of distinguished individuals to be appointed by the Presidents of both the National Academy of Sciences and the National Academy of Engineering. This panel will select the most outstanding proposals for detailed consideration by the Department of Energy, which will make the final decision.

International Cooperation in Particle Physics

There is no national science, just as there is no national multiplication table.

Anton Chekhov

Ever since Isaac Newton ushered in the Age of Reason in the late seventeenth century, science has been among those human pursuits least affected by the vagaries of political and social influence. Although there have been occasional episodes of prescribed scientific dogma in totalitarian states, these have invariably been doomed to failure. Science demands rigorous self-scrutiny, and it has thrived on the free exchange of ideas among its practitioners all over the world.

The truly fundamental advances in science are still largely the product of individual genius, whose encouragement cannot be overvalued. The environment in which such breakthroughs are fostered, however, is increasingly that of a collaboration of scientists working on a given problem. This is especially true of experimental research, and nowhere more so than in particle physics. With Lawrence's invention of the cyclotron came the era of "big science," in which large facilities, and large interdisciplinary teams of specialists to design and build them, are essential to further progress.

Since the earliest days of cyclotron experiments in Berkeley, forefront accelerators have attracted scientists from far and wide to engage in research, or even to participate in their design and construction. They come from foreign countries to learn new techniques, to impart their own expertise, and to do experiments that might not be possible elsewhere. Both visitor and host benefit from the exchange of ideas, as do the students who are exposed to them. The pace of scientific progress is accelerated, and international ties are strengthened.

Some visiting scientists—whether from abroad or from elsewhere in the host country—collaborate on an informal, individual basis with their colleagues. Others may be members of organized teams of investigators who engage in more formal, institutional collaborations on one or more experiments. Either way, proposed experiments are typically evaluated, and

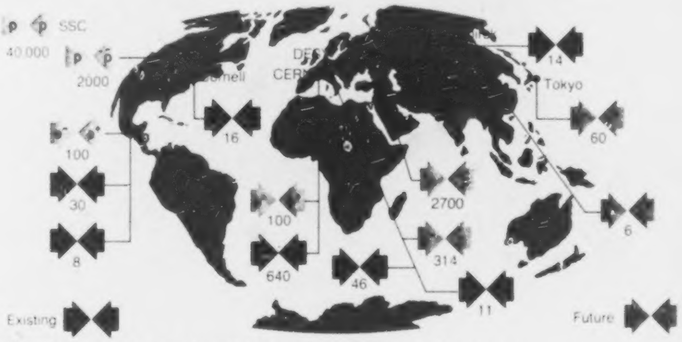
> *The open society, the unrestricted access to knowledge, the unplanned and uninhibited association of men for its furtherance—these are what may make a vast, complex, ever growing, ever changing, ever more specialized and expert technological world, nevertheless a world of human community.*
>
> J. Robert Oppenheimer

approved or rejected, solely on the basis of scientific merit, without regard for the nationalities of those involved. Often the advisory committees who make these decisions are themselves international in composition.

For most of the past half-century, the United States was clearly pre-eminent in particle physics in the world. Foreign physicists gravitated to our shores to avail themselves of the incomparable research facilities at our major accelerators. During the past decade, however, the balance has shifted somewhat. More and more American physicists are now traveling overseas to conduct their research at the leading accelerators in Europe and Japan. These have been built with an increasing awareness of the national significance of such facilities, not just as major research centers but also as centers of higher education in physics, as sources of technological innovations that can be transferred to domestic industries, and as symbols of national prestige.

Often physicists work at their home institution on the design, construction, and testing of new particle detectors that are to be used at accelerators abroad. Some of these detectors can occupy a large team of specialists for many years. Among the foreign accelerator centers at which Americans have participated in the construction of such detectors in recent years are CERN (Geneva), DESY (Hamburg), and KEK (Tsukuba, Japan). Owing to the significant research opportunities outside the United States, there are fewer European, Japanese, and other foreign scientists involved in major experiments at U.S. accelerators. Nonetheless, their participation in large collaborations here is often important (see facing page).

It is hoped that the SSC will foster a new level of international cooperation in particle physics. As the premier accelerator in the world, it will surely attract many of the best particle physicists from overseas as well as from this continent. Active international collaborations may be established early enough to allow significant foreign participation in the design and construction of the SSC and its detectors, not just in their utilization.



The world's colliding-beam accelerators; the ones designated "future" are either under construction or being planned. (CERN is in Geneva, DESY is in Hamburg.) The colliders are labeled according to the kinds of particles used: e^- for electrons, e^+ for positrons, p for protons, and $\bar{p}$ for antiprotons. The numbers represent the maximum total collision energy in billions of electron volts, or GeV (1 GeV = 0.001 TeV).

End view, showing the magnet coil in place, of the Collider Detector at Fermilab, presently under construction. As shown by the flags, this is a joint effort by teams of physicists and engineers from Japan, the United States, and Italy. (Courtesy of Fermi National Accelerator Laboratory.)

The SSC in Higher Education

A professor can never better distinguish himself in his work than by encouraging a clever pupil, for the true discoverers are among them, as comets amongst the stars.
CAROLUS LINNAEUS

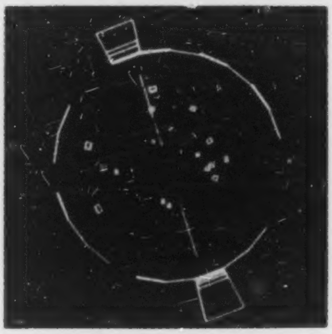
Accelerator laboratories and other basic research facilities are much more than vehicles of scientific progress. They are among the best training grounds for many of our brightest students, whose future scientific leadership will play an important role in our universities, high-technology industries, and government. The challenge of working with top-ranking scientists at forefront research facilities cannot be duplicated in any other environment.

A necessary prelude to the research at accelerators is the development of particle detectors, without which the accelerators would be useless. Much of this work is conducted at leading universities, typically with the participation of graduate students in physics and various engineering disciplines. Among the most complex and sophisticated instruments ever invented, particle detectors—each having unique capabilities tailored to the research problem at hand—provide many opportunities for students to learn the practice of particle physics as well as its principles.

At the "hands-on" level, this practice encompasses such diverse skills as the design of high-speed electronic circuitry, high-precision optical and mechanical devices, and advanced cryogenic systems. A substantial knowledge of computer programming and data processing systems is indispensable. The high event rates and enormous amounts of data typically encountered require the development of superior decision-making ability in order to select the small fraction of events that are of genuine interest. All of this work provides training in large-scale systems analysis and management, which are increasingly vital skills in the modern technological world. Among scientific disciplines, particle physics is probably unique in its level of such training.

The essentially one-on-one relationship between graduate student and thesis adviser that is typical in most fields of physics is seldom possible in the complex environment of accelerator-based research, where large, interdisciplinary teams of investigators are the norm. Yet this very complexity provides much of the challenge and excitement of research in particle physics. The exceptional demands that it places on the student are an integral part of his or her education. Equally valuable is the experience of working closely with a group of experts who constitute, in effect, a whole team of teachers.

The typical graduate student's experience in experimental particle physics includes about two years of course work accompanied by research training on a detector project. Subsequently, the student might spend one or two years working at an accelerator, setting up and debugging equipment and collecting experimental data. The culmination of this work is an independent research project, lasting from one to three years, requiring the analysis and interpretation of these data. Throughout the time spent at the accelerator, the student is enriched and matured by associations with engineers and technicians, with students and faculty members from other institutions, and with physicists at all stages of their



Computer-graphic simulation of a collision event at the Tevatron at Fermilab. (Courtesy of Fermi National Accelerator Laboratory.)

careers, including visitors from around the world.

This kind of training provides a solid background for a career in particle physics, but it can also be readily translated to other endeavors. Indeed, it is not uncommon for some physicists eventually to gravitate to another field, such as biology or computer science, bringing with them the physical insights and mathematical rigor of their own discipline. It is intriguing to note that a number of major advances in molecular biology in the past few decades have been made by such "transplanted" physicists, several of whom have been awarded the Nobel Prize in Medicine and Physiology for their discoveries.

The SSC will be both a symbol of America's commitment to scientific leadership into the twenty-first century and an instrument by which that leadership can be maintained. As such, it will undoubtedly stimulate new interest in particle physics and attract increasing numbers of top students to the field. Whether these students remain in particle physics or go on to meet new challenges, the unique educational experience that many of them will receive at the SSC will surely benefit our society in varied ways.

Particle Physics and Society

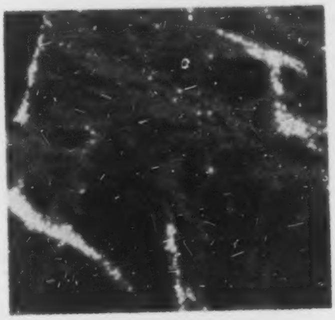
There are science and the applications of science, bound together as the fruit to the tree which bears it.

Louis Pasteur

Toward the end of the nineteenth century, many physicists believed that all the major problems had been solved. There was little left to do, they thought, but refine existing knowledge to higher levels of precision. Students were advised to avoid physics as a career, because it was a "closed book."

But in 1895, Wilhelm Rontgen discovered x rays in cathode-ray tubes. Two years later, J. J. Thomson identified their source as accelerated electrons. (Thus cathode-ray tubes, which are still with us—in TV sets, for example—were actually the first particle accelerators.) The importance of these two discoveries was quickly realized. They spawned prodigal bursts of discovery and invention that revolutionized physics, medicine, and every other field of science and technology.

The common heritage of x rays and accelerators is still evident today. Most modern x-ray machines are based on vacuum tubes similar to the early models, although they are much refined. Other, more powerful ones are actually small linear electron accelerators closely related to



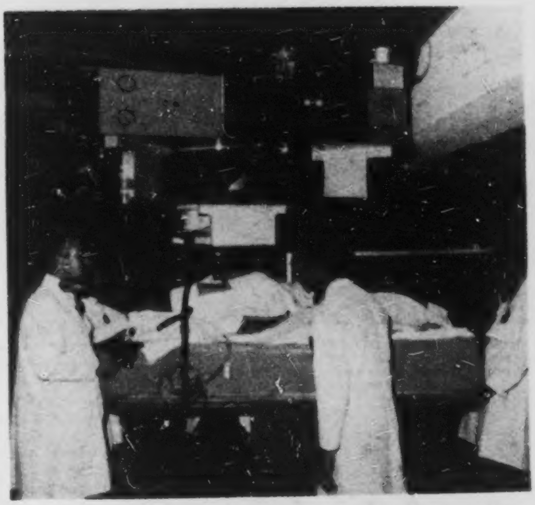
A specimen of human skull tissue, 25 micrometers across, photographed with x rays from a synchrotron radiation source (an electron synchrotron). A computer-generated false color scale is used to reveal the density distribution of calcium; the black areas show a loss of this element. By studying such specimens, it may be possible to evaluate the therapeutic efficacies of various treatments for osteoporosis, a common degenerative bone disease. This work is a collaboration between the State University of New York at Stony Brook and the National Synchrotron Light Source at Brookhaven. (Courtesy of Brookhaven National Laboratory.)

those used for particle physics research. These instruments are invaluable not only in medical practice but also in a wide variety of industrial applications, such as the inspection of structural materials for potentially dangerous defects.

On a much larger scale, high-energy electron synchrotrons are being used as sources of intense beams of radiation, at wavelengths from x rays through ultraviolet and optical to infrared. Called *synchrotron radiation*, it is emitted by electrons that are accelerated through a curved path. The higher the energy or the tighter the curve, the greater the rate at which the electrons emit this radiation. These factors conspire to impose practical upper limits on the energies of electron synchrotrons. (Electrons are thus ruled out as the particles to be accelerated at the SSC; protons, which emit virtually no synchrotron radiation because of their much greater mass, win by default.)

Synchrotron radiation, the bane of particle physicists who seek the highest possible electron energies, has become a boon for scientists in other fields. For them, the extraordinary spectral brilliance of the most powerful sources of this radiation is expanding the capabilities of many existing experimental techniques and opening up entirely new ones. From investigations of complex surface-catalysis mechanisms, ultrafast photochemical reaction rates, and new life-saving medical diagnostic techniques to biological microholography of living specimens and x-ray lithography of microelectronic circuits, the use of synchrotron radiation offers great potential for benefits to society through scientific advances on many fronts.

Research of these kinds is being vigorously pursued at the National Synchrotron Light Source at Brookhaven National Laboratory, the Stanford Synchrotron Radiation Laboratory at the Stanford Linear Accelerator Center, and growing numbers of other accelerator facilities both in the United States and abroad.



Experimental cancer therapy using a beam of charged pions at the Los Alamos Meson Physics Facility. When these particles are stopped by matter, after traversing a characteristic thickness of it, their mass is converted to energy. Thus the malignant cells can be given a large dose of radiation with relatively little damage to surrounding healthy tissue. (Courtesy of Los Alamos National Laboratory.)

The impact of particle physics on society is sometimes more tangible and direct, however. New instruments or techniques of basic research can yield new products and services to enhance the quality of our lives and the health of our economy. The linear-accelerator x-ray machine mentioned above is a case in point. Another example, not quite as direct but no less significant, is the digital computer. The first binary computing element was derived from the scaling circuits originally developed for particle counters used at accelerators. The enormous computational demands of accelerator-based research, together with the need for miniaturization of many of its electronic devices, have continued to spur the rapid

A cable-winding machine used for the fabrication of superconducting cables. Each copper wire contains hundreds of individual superconducting filaments made of a niobium-titanium alloy. (Courtesy of Lawrence Berkeley Laboratory.)

Cross-sectional view of a superconducting wire, etched with nitric acid and artificially colored to reveal the ends of the niobium-titanium filaments. Their diameter is 10 micrometers. (Courtesy of Lawrence Berkeley Laboratory.)

Superconductivity

Faraday's discoveries in electricity and magnetism overshadowed his pioneering work in a seemingly unrelated field: the liquefaction of gases at very low temperatures. Long after his death, however, these separate paths suddenly converged to reveal an astonishing phenomenon, superconductivity, whose industrial applications may one day rival those of microelectronics.

In the domain of the ultracold, near absolute zero on the temperature scale, many metals and alloys lose all trace of their electrical resistivity and become *superconductors*. If an electric current is started in a superconducting loop and the power source is then removed, the current will continue to flow virtually forever—as long as the temperature is maintained below a critical value that is characteristic of the material. Such a loop can be used to make an electromagnet whose coils have no power loss whatever. In conventional electromagnets, power loss occurs in the form of resistive heating, which increases rapidly with the current.

Superconducting magnets have two great advantages over conventional ones: (1) they can sustain much higher currents and therefore produce much higher field strengths, and (2) once started, they can run indefinitely on nothing but the power required to maintain the refrigeration. (Thus, although there is still no free lunch, it can be made relatively inexpensive.) The disadvantage of these magnets (those that are designed for accelerators) is that they are more expensive to build than conventional ones. The long-range saving in power costs, however, is much greater than the additional cost of construction.

Superconductivity was discovered in 1911 by Heike Kamerlingh Onnes in the course of his research on liquid helium. It remained an inexplicable laboratory curiosity until the 1950s, when its quantum mechanical nature was brilliantly elucidated. Not until the 1960s, however, was it finally put to practical use, notably in detector magnets for nuclear and particle physics research. This led, in 1983, to the crowning achievement of this technology in the superconducting Tevatron ring at Fermilab.

But this is just one facet of superconductivity. Beyond its uses in basic research lie many potential commercial applications. Among these are low-cost transmission lines for electric power, magnetically levitated trains of extreme speed, new energy-storage systems, and new magnetic imaging systems for medical diagnostics. Equally exciting are the prospects for SQUIDS (superconducting quantum interference devices), whose uses range from mineral prospecting to brain research to the design of ultrafast computers. Faraday would be astounded.

> *We know very little, and yet it is astonishing that we know so much, and still more astonishing that so little knowledge can give us so much power.*
>
> BERTRAND RUSSELL

growth of the computer industry. The creativity and competitiveness of this industry's entrepreneurs—many of them former research physicists—have now brought the computer revolution within virtually everyone's reach.

Or consider the communications industry, which would be primitive indeed without the high-power oscillator tubes used for signal broadcasting. These tubes were first developed for linear electron accelerators. Their invention would not have been possible without knowledge of the physical principles upon which their operation rests, and this knowledge was gained through basic research. Thus, the high-power oscillator tube not only closed a vital research/technology feedback loop but also spun off into major industrial applications.

In contributing to the growth, even the very existence, of multibillion-dollar industries, physics research pays society back handsomely for the financial support that it receives. Of course, smaller industries are also a part of this equation. It is difficult, in fact, to think of *any* technology that has not been affected, directly or indirectly, by basic research into the most fundamental aspects of matter and energy.

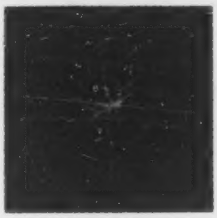
The technological spin-offs from basic research are not, however, the only way in which accelerators have an impact on modern industry. The construction itself of these complex instruments and their particle detectors makes extraordinary demands on the industries involved. Among these are such advanced technologies as superconducting magnets, electronics, cryogenics, and computers. They also include more conventional ones, such as soil and foundation engineering, construction, and utilities.

The SSC will provide new challenges to these and other industries by requiring many products and services, on a large scale, at the limits of our technological capabilities. The advances that result from such a stimulus will enhance the competitive position of American industries in the world marketplace and will allow still higher standards to be set for the accelerators of the future.

Just as important as the contributions that physics research makes to our industrial strength is the role that it plays in our culture. We are a society that has cast its lot with the rational view of nature: the belief that the universe is comprehensible through the application of reason and the discovery of experimental facts. Everything in the universe is held to be the consequence of fundamentally simple laws that are the same throughout all space and time.

It is the role of particle physics, more than any other science, to discover exactly what these laws are. Doing so helps to shape our conception of our own world and its place in the cosmos. The better our understanding of whence we have come, and how, the better we will understand where we are going, and why.

The SSC is an instrument conceived for the pursuit of this age-old goal. In this brochure, we have attempted to show how it will enrich our culture through advances in scientific knowledge and the expansion of our technological prowess. We cherish the hope that the spirit of international cooperation among physicists from many nations, working together at the SSC, will help strengthen the ties that bind us all. And we envision the SSC as a major force in the education of many of our finest young scientists, who will continue the quest long after we are gone.



Bibliography

Popular Articles

J. Boslough, Worlds Within the Atom, *National Geographic*, May 1985 (in press).

R. Gore, The Once and Future Universe, *National Geographic*, June 1983, p. 704.

J. S. Trefil, Closing in on Creation, *Smithsonian*, May 1983, p. 33; How the Universe Will End, *Smithsonian*, June 1983, p. 72.

More Technical Articles

T. Appelquist, M. K. Gaillard, and J. D. Jackson, Physics at the Superconducting Super Collider, *American Scientist*, March-April 1984, p. 151.

R. Diebold, The Desertron: Colliding Beams at 20 TeV, *Science*, 7 October 1983, p. 13.

M. K. Gaillard, Toward a Unified Picture of Elementary Particle Interactions, *American Scientist*, September-October 1982, p. 506.

H. Georgi, A Unified Theory of Elementary Particles and Forces, *Scientific American*, April 1981, p. 48.

H. Harari, The Structure of Quarks and Leptons, *Scientific American*, April 1983, p. 56.

G. 't Hooft, Gauge Theories of the Forces between Elementary Particles, *Scientific American*, June 1980, p. 104.

L. Lederman, The Value of Fundamental Science, *Scientific American*, November 1984, p. 40.

D. N. Schramm, The Early Universe and High-Energy Physics, *Physics Today*, April 1983, p. 27.

C. Sutton, The Biggest Microscopes in the World, *New Scientist*, 13 September 1984, p. 37.

V. F. Weisskopf, The Three Spectroscopies, *Scientific American*, May 1968, p. 15.

R. R. Wilson, The Next Generation of Particle Accelerators, *Scientific American*, January 1980, p. 42.

Popular Books

J. D. Barrow and J. Silk, *The Left Hand of Creation*, Basic Books, New York, 1983.

G. Feinberg, *What Is the World Made Of?*, Anchor Press/Doubleday, Garden City, N.Y., 1977.

H. Fritzsch, *The Creation of Matter*, Basic Books, New York, 1984.

H. Fritzsch, *Quarks*, Basic Books, New York, 1983.

M. Goldsmith and E. Shaw, *Europe's Giant Accelerator*, Taylor & Francis Ltd., London, 1977.

P. J. Hilts, *Scientific Temperaments*, Simon and Schuster, New York, 1982.

R. Jungk, *The Big Machine*, Charles Scribner's Sons, New York, 1968.

M. S. Livingston, *Particle Accelerators: A Brief History*, Harvard University Press, Cambridge, Mass., 1969.

H. Pagels, *The Cosmic Code*, Simon and Schuster, New York, 1982.

J. C. Polkinghorne, *The Particle Play*, W. H. Freeman and Co., San Francisco, 1979.

J. Silk, *The Big Bang*, W. H. Freeman and Co., San Francisco, 1980.

C. Sutton, *The Particle Connection*, Simon and Schuster, New York, 1984.

J. S. Trefil, *From Atoms to Quarks*, Charles Scribner's Sons, New York, 1980.

J. S. Trefil, *The Moment of Creation*, Charles Scribner's Sons, New York, 1983.

R. V. Wagoner and D. W. Goldsmith, *Cosmic Horizons*, W. H. Freeman and Co., San Francisco, 1982.

S. Weinberg, *The Discovery of Subatomic Particles*, Scientific American Books, New York, 1983.

S. Weinberg, *The First Three Minutes*, Basic Books, New York, 1977.

More Technical Books

L. M. Brown and L. Hoddeson, eds., *The Birth of Particle Physics*, Cambridge University Press, Cambridge, 1983.

J. E. Dodd, *The Ideas of Particle Physics*, Cambridge University Press, Cambridge, 1984.

Report of the Reference Designs Study Group on the Superconducting Super Collider, May 8, 1984, available from the Division of High Energy Physics, U.S. Department of Energy, Washington, DC 20545.

Glossary

Accelerator A device that increases the speed, and thus the energy, of charged particles such as electrons and protons.

Antiparticle A particle that is identical to an ordinary particle except for having certain opposite elementary properties, such as electric charge.

Antiproton The negatively charged antiparticle of the proton.

Atom The smallest unit of a chemical element, consisting of a central nucleus surrounded by orbital electrons. It is held together by the electromagnetic force.

Big Bang The cataclysmic event believed to have been the origin of the universe about 15 billion years ago.

Boson Any member of a class of particles that have integral values of spin. The fundamental forces are mediated by bosons.

CERN The European Organization for Nuclear Research, in Geneva.

Collider An accelerator in which two beams of particles collide head-on.

Cosmic rays Extremely energetic particles that bombard the earth from outer space.

Cyclotron An accelerator in which the charged particles spiral outward from the center of the machine.

DESY The German Electron Synchrotron Laboratory, in Hamburg.

Detector Any device that can detect the presence of a particle or nuclear fragment and measure one or more of its physical properties.

Electromagnetic force A long range force associated with the electric and magnetic properties of particles. It is mediated by photons.

Electron A light, negatively charged lepton that is a constituent of all atoms. It has only $1/1836$ the mass of a proton.

Electron volt A unit of energy used in particle physics, equal to the energy gained by an electron that is accelerated through a potential difference of one volt. It is used to express either the energy or the mass of a particle (in accord with relativity). See also GeV and TeV.

Electroweak force A fundamental force comprising the unified electromagnetic and weak forces.

Elementary particle A particle that has no apparent substructure, i.e., that cannot be subdivided into other particles. The known elementary particles are quarks, leptons, and force-carrying bosons.

Fixed-target accelerator An accelerator in which a single beam of particles collides with a stationary target.

GeV One billion (10^9) electron volts.

Gluon Any of eight massless bosons that are the carriers of the strong force.

Grand Unified Theory A mathematical formalism for unifying the strong and electroweak forces. The correct Grand Unified Theory has not yet been formulated.

Gravitation A long-range force that affects all particles. It is so weak that it is manifest only in macroscopic objects.

Graviton The hypothetical massless boson that is the carrier of the gravitational force.

Higgs boson A hypothetical, extremely massive boson arising in the theory of the electroweak force. The search for this particle is one of the objectives of the SSC.

Injector An accelerator whose beam is injected into another, higher-energy accelerator.

KEK The National High-Energy Physics Laboratory of Japan, in Tsukuba, near Tokyo.

Kinetic energy The energy associated with the motion of any object.

Lepton Any of six elementary particles that experience the weak force but not the strong force. The known leptons are the electron, muon, tau, and their three associated neutrinos. There are also six corresponding antileptons.

Linear accelerator An accelerator in which the charged particles travel in a straight path.

Luminosity A collider parameter that specifies the frequency with which collisions occur.

Muon A lepton that appears identical to the electron except for its greater mass.

Neutrino Any of three uncharged, apparently massless leptons, each associated with one of the charged leptons.

Neutron An uncharged composite particle found in all atomic nuclei except that of ordinary hydrogen. Its mass is almost identical to that of the proton.

Nucleus The tiny, dense, central core of an atom, composed of protons and neutrons held together by the strong force.

Particle physics The study of the properties of subnuclear particles, both elementary and composite, and the forces through which they interact.

Photon A massless boson that is the carrier of the electromagnetic force. All electromagnetic radiation consists of photons.

Positron The positively charged antiparticle of the electron.

Proton A positively charged composite particle found in all atomic nuclei. It is the particle that will be accelerated in the SSC.

Quark Any of six fractionally charged elementary particles that experience the strong force and that appear to exist only in combinations of two or three. There are also six corresponding antiquarks.

Standard Model The combined, but not yet mathematically unified, theories of the strong and electroweak forces, incorporating the concepts of quarks, leptons, and force-carrying bosons. It is the foundation of particle physics and nuclear physics.

Strong force A short-range force, the strongest one known, that affects quarks and all the particles composed of quarks.

Superconductivity The ability of some materials to maintain perpetual electric currents without loss, owing to the complete absence of electrical resistance. It occurs at very low temperatures.

Synchrotron An accelerator in which the charged particles are constrained to a circular orbit. The SSC will be a proton synchrotron.

Synchrotron radiation The electromagnetic radiation emitted by charged particles, mainly electrons, moving along a curved path.

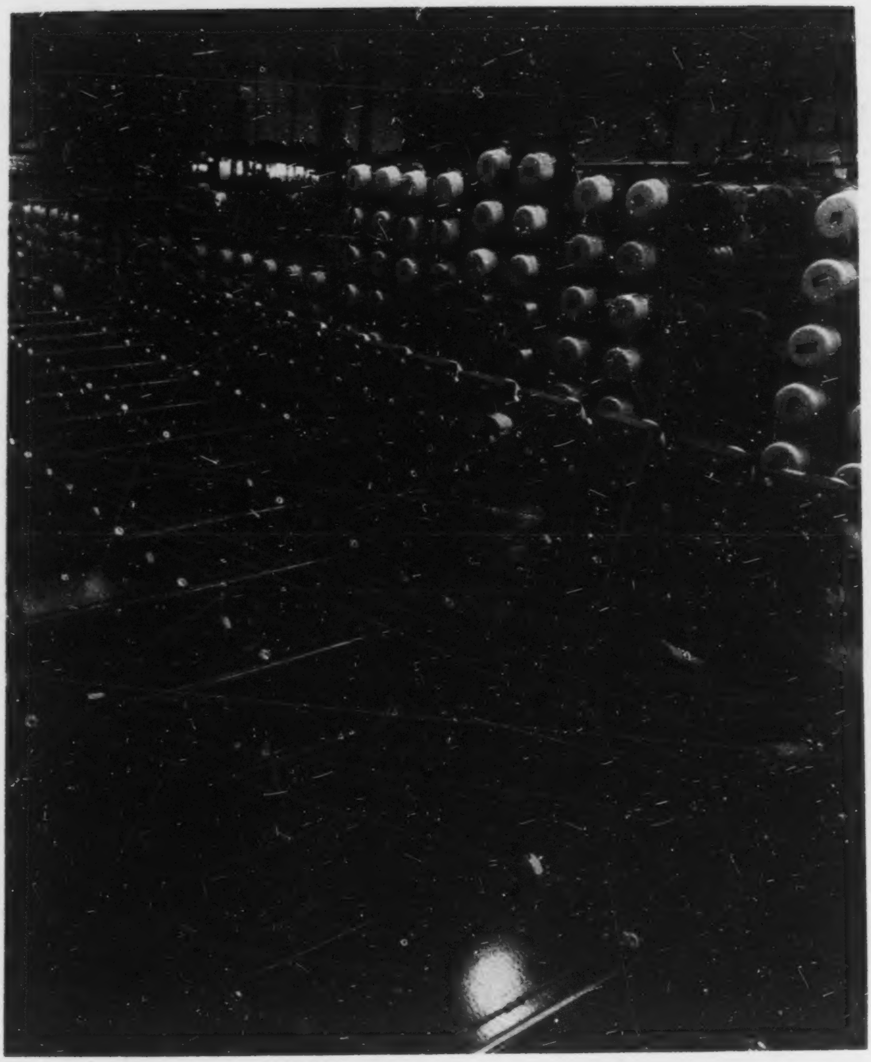
Tau lepton A lepton that appears identical to the electron except for its much greater mass.

TeV One trillion (10^{12}) electron volts.

W^+, W^-, and Z^0 bosons The three massive bosons that are the carriers of the weak force.

Weak force A short-range force that affects all quarks and leptons. It is responsible for the decays of many particles.

Opposite: A storage area in the "magnet factory" at Fermilab, showing stacks of superconducting magnets waiting to be installed in the main ring to create the Tevatron accelerator. The Tevatron began operation in 1983. (Courtesy of Fermi National Accelerator Laboratory.)



SSC-15

Superconducting Super Collider

Siting Parameters Document

A Technical Advisory on
SSC Site Criteria and
Catalog of Site Information Needs

June 15, 1985

SSC Central Design Group
Universities Research Association
c/o Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

LEGAL NOTICE

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Lawrence Berkeley Laboratory is an equal opportunity employer.

SUMMARY

The Superconducting Super Collider, or SSC, is a proposed scientific instrument for the study of the fundamental nature of matter. In the SSC two 20-TeV beams of protons will be accelerated and counter circulate on an approximately circular path. The protons will be made to collide at six locations where detectors can be placed to count and measure the products of the collisions. These collisions, twenty times more energetic than in any existing facility, will enable scientists to probe deeper into the heart of matter in the quest for a deeper understanding of the universal forces of nature.

The goal of the SSC project is to create a scientific laboratory in high energy physics whose facilities are unique. Ultimately the success of that laboratory will be measured by its scientific discoveries, measurements, interpretations, and innovations. Toward that end the accelerator-collider must be constructed to high standards at minimum cost and maximum effectiveness. Preparations must be made for future operations and a scientific-technical staff attracted and maintained. The chosen site must accommodate all of these factors.

This document summarizes siting criteria for the SSC and enumerates site-specific information important to the evaluation of potential sites. This document is not a call for site proposals but a technical report prepared for the information and use of the Department of Energy (DOE).

The Reference Designs Study (RDS), published in May 1984, examined three technological approaches to a proposed 20-TeV proton collider. The site criteria presented here are derived largely from the RDS. Final details of the facility layout and building structures required will depend upon the actual site. The RDS is a model of such a facility that meets the scientific criteria and provides adequate working space for the activities and personnel associated with the SSC. The central feature of the facility will be a tunnel buried at least 20 feet below the local ground surface. The minimum circumference of this more or less circular tunnel is determined by the strength of the magnetic field that guides the beam along its path. Two field strengths, 3 and 6 tesla, are now under consideration and a choice will be made and announced by the end of September 1985. These correspond respectively to circumferences of about 100 and 60 miles.

An injector complex serves as the source of the protons to be accelerated in the collider ring. Its major feature will be a ring tunnel approximately five percent of the circumference of the collider ring. The location of the injector complex on the perimeter of the collider ring can be arranged to suit a site.

The loci of principal experimental physics work will be collision halls housing the detectors at the interaction points, together with adjoining areas where beams derived from the collider ring beams may be used for tests/experiments. These six halls may be distributed evenly around the ring in a periodic manner or they may be clustered in two or three groups. A study of the feasibility of clustering will be complete by the end of September 1985.

While the total space required for laboratories, shops, offices, warehouses, and auxiliary equipment will be approximately as described in the RDS, their form and placement has considerable flexibility for adaptation to a particular site. The bulk of the area within the collider ring will be totally unaffected by the presence of the facility, although control of and access to the associated surface buildings will be required.

The relevant site criteria and desired information fall into the following broad categories:

Physical Setting. A site must accommodate the accelerator, conceived of as a planar ring 60 to 100 miles in circumference with the possibility of a slight tilt to accommodate the profile of the land, and must have available up to 11,000 acres of land appropriately distributed around the ring.

Environmental Aspects. A site should be such that the SSC facility can be positioned, constructed, and operated in an environmentally acceptable way.

Geology and Tunneling. The geology of a site must be such as to allow efficient tunneling with resulting structural stability and without encountering excess water.

Community Resources. A site should provide year-round access by road, have a major airport nearby, have adequate housing and educational facilities potentially available for the staff, and adequate industrial and construction resources in the vicinity.

Utilities. A site should have available adequate and reliable water (up to 2000 gal/min) and electrical power (up to 250 MW).

Man-Made Disturbances. Accelerator operation requires avoidance of excessive very low frequency noise and vibration adjacent to the tunnels.

Climate. Ease of construction, and cost and reliability of operation of the facility make desirable the avoidance of extremes of temperature and humidity.

Cost and Schedule Factors. Economies in construction and operation as well as proposed cost sharing for land, preferential utility rates, and similar items are important considerations.

Part III of this report gives more precise and detailed statements of the site criteria including numerical values where appropriate. Part IV itemizes the detailed information desired in order to make an informed evaluation of any site.

Approximately 3000 scientists, engineers, and technicians will operate the facility and carry out its scientific work. The environmental impact of the facility will be similar to that of a campus of a university or a corporate research center. It is estimated that the capital cost of the facility itself, together with the initial complement of scientific equipment, pre-operating costs, and R & D, will be about $4 billion (in FY-1984 dollars). A construction time of about six years between notice to proceed and completion is anticipated.

The principal objective of this advisory is to delineate for the Department of Energy those technical factors affecting the choice of a site for the SSC. The goal is the creation of a laboratory that will ensure the capability and effectiveness of the U.S. research program in elementary particle physics well into the next century.

More information of the research potential of the SSC is contained in a booklet, "To the Heart of Matter -- The Superconducting Super Collider," and the articles and books cited in its bibliography. Copies of this informational booklet are available from the SSC Central Design Group.

TABLE OF CONTENTS

PART I. SSC PROJECT DESCRIPTION

A. INTRODUCTION 1
B. DESCRIPTION OF THE SSC 4
    1. The Injector Facility. 5
    2. The Collider Ring. 5
    3. The Experimental Areas 6
    4. The Campus Area. 7
C. ESTIMATED COST AND SCHEDULE. 7
D. ENVIRONMENTAL IMPACT AND RADIATION SAFETY. 8
E. RECENT CHRONOLOGY OF THE PROJECT 9

PART II. FEATURES OF THE SSC FACILITY

A. CONSTRUCTION FEATURES. 15
B. TABLE OF TECHNICAL FEATURES OF THE SSC 17
C. TABLE OF FACILITY PARAMETERS FOR THE SSC USING 6-T MAGNETS . . . 18
    1. General. 18
    2. Area 18
    3. Above-Ground Buildings 18
    4. Below-Ground Enclosures. 18
    5. Utilities. 18
D. TABLE OF FACILITY PARAMETERS FOR THE SSC USING 3-T MAGNETS . . . 19
    1. General. 19
    2. Area 19
    3. Above-Ground Buildings 19
    4. Below-Ground Enclosures. 19
    5. Utilities. 19

PART III. SSC SITING CRITERIA

A. SETTING 21
B. ENVIRONMENT 22
C. GEOLOGY AND TUNNELING. 22
D. COMMUNITY RESOURCES. 23
E. UTILITIES. 24
F. MAN-MADE DISTURBANCES. 24
G. CLIMATE. 25
H. COST AND SCHEDULE 25

PART IV. INFORMATION NEEDED ABOUT PROPOSED SITES

A. SETTING. 28
    1. General. 28
    2. Land Commitment. 28
    3. Institutional Setting. 29
        a. Regulations. 29
        b. Taxation 29
        c. Employment Practices 29
    4. State and Local Government Support 30
B. ENVIRONMENT. 31
    1. Land Use 31
    2. Surface Water. 31
        a. Quantity 31
        b. Quality. 32

- c. Flooding/Drainage . . . 32
- d. Low Flow/Drought . . . 32
- 3. Ecology . . . 33
  - a. Fish and Wildlife . . . 33
  - b. Vegetation . . . 33
- 4. Air Quality . . . 33
- 5. Background Radiation . . . 34
- 6. Historical and Archaeological Resources . . . 34
- 7. Preliminary Environmental Evaluation . . . 34

C. GEOLOGY AND TUNNELING . . . 35
- 1. Topography . . . 35
- 2. Geology . . . 35
- 3. Geohydrology . . . 36
- 4. Seismicity . . . 36
- 5. Tunneling and Underground Construction . . . 37

D. COMMUNITY RESOURCES . . . 37
- 1. Human Resources . . . 37
- 2. Housing and Community Services . . . 38
  - a. Housing . . . 38
  - b. Community Services . . . 38
- 3. Accessibility . . . 38
  - a. Airports . . . 39
  - b. Highways, Streets, and Roads . . . 39
  - c. Public Transportation . . . 39
  - d. Railroads and Waterborne Transportation . . . 40
- 4. Construction Resources . . . 40
- 5. Industrial Resources . . . 40
- 6. Educational and Cultural Resources . . . 41
- 7. Community Support and Assessment . . . 42

E. UTILITIES . . . 42
- 1. Power . . . 42
- 2. Fuel . . . 43
- 3. Water . . . 44
  - a. Industrial Cooling . . . 44
  - b. Potable . . . 45
- 4. Waste Disposal . . . 45
  - a. Sewage Disposal . . . 45
  - b. Solid Waste Disposal . . . 45
- 5. Telecommunications . . . 46

F. MAN-MADE DISTURBANCES . . . 46
- 1. Vibration . . . 46
- 2. Noise . . . 46

G. CLIMATE . . . 47
- 1. Temperature and Humidity . . . 47
- 2. Precipitation . . . 47
- 3. Wind . . . 48
- 4. Regional Storms . . . 48
- 5. Insolation . . . 48

H. COST AND SCHEDULE . . . 48
- 1. Cost Factor . . . 48

PART I. SSC PROJECT DESCRIPTION

A. INTRODUCTION

The proposed Superconducting Super Collider (SSC) will be one of the largest scientific instruments ever made: its major feature is a giant ring— up to 100 miles in circumference— in which the basic constituents of matter are created and studied at an energy of 40 trillion electron volts, twenty times greater than at any existing facility. Particle physicists here and abroad agree that the construction of the SSC within a decade will give scientists timely access to an instrument unrivaled in the world for making frontier discoveries well into the next century.

To the passerby or guest who visits the SSC some time after its completion in the mid-1990s, the focal point of the site will present the appearance of a university or research center campus, with a central multistory office building, numerous laboratories, shop buildings, and other support buildings. The heart of the facility, a ring-shaped or oval tunnel 60 to 100 miles in circumference and about nine feet in inside diameter, is buried many feet under the ground, while the landscape above it gives few clues to what lies beneath. Where the ring passes below farm land, crops grow and cattle graze; where it traverses forests and remote areas, the land yields no signs of construction; where it passes under highways, towns, and rivers, life goes on as usual. Every two to four miles, small surface buildings— containing power supplies, support facilities, and points of access— connect to the tunnel, and at several locations around the ring larger complexes of buildings signal the location of interaction regions containing detectors for experiments. Figure 1-1 is a possible bird's eye view of a site. Some 3000 men and women will be working on any particular day at the SSC facility— scientists and engineers and technical and administrative staff— including 500 visitors taking part in research projects.

The SSC is a particle accelerator, one of a family of scientific instruments that has been in the forefront of scientific discovery in the twentieth century. The development of particle accelerators, coupled with the discovery of natural radioactivity earlier in the century, led directly to the establishment of the field of science known as high energy physics, a field in which American scientists have made major contributions.

High energy physics, often called particle physics, is the study of the ultimate constituents of matter. The particle accelerator is its chief tool because with the collisions of very energetic particles, scientists can observe in a direct way the basic building blocks of nature and the forces that hold them together. The progression from the first cyclotron, 5 inches in diameter, to the proposed SSC, 20 to 30 miles in diameter, is a direct consequence of the need to probe at ever smaller distances, deep into the heart of matter.

Accelerators work by using a series of electromagnetic kicks to boost charged particles like protons (the nuclei of hydrogen atoms), or electrons to ever-higher energies. When they reach their maximum energy the particles are directed against a target that contains either the same or other types of particles. The collisions cause the release of substantial bursts of energy, out of which new forms of matter emerge. The resulting particles are detected and studied in large-scale electronic detectors that measure such basic characteristics as energy, electric charge, mass, and lifetime. In this manner, particle physicists illuminate the interconnections that exist among the fundamental laws of nature and gain insight into the generation of matter.

Accelerators can be configured in straight lines, in which case the particles are accelerated by passing once through a series of electric fields. The largest such linear accelerator, or linac, is the two-mile-long machine at the Stanford Linear Accelerator Center (SLAC) in California.

Most present-day high-energy accelerators, however, are circular. In the cyclotron, invented by the American physicist Ernest Lawrence, particles circle in a magnetic field and on repeated revolutions pass through a constant-frequency alternating electric field that adds small amounts of energy on each pass. This causes the particles gradually to spiral outward to a maximum radius while gaining energy. In the cyclotron, the time for a particle to make one orbit is constant.

The design of the cyclotron was improved upon in the forties and fifties by the invention of the synchrocyclotron and the synchrotron, which allowed physicists to generate beams of particles at much higher energies. In such machines, the frequency of acceleration is synchronized with the particle as it makes successive orbits, the time for each particle to orbit the machine varying with change in particle energy. The synchrocyclotron has an unchanging magnetic field, but an accelerating electric field whose frequency is decreased gradually as the outwardly spiraling particles take longer and longer to make successive revolutions as they gain energy. The synchrotron, on the other hand, maintains a fixed orbit radius for the particles, varying both the magnetic field and the frequency of the accelerating electric field in time as the particles gain energy. An important virtue of the synchrotron is that the guiding field around a large circumference is provided over only a small volume within a ring of magnets. This approach leads to economy in construction as well as in operating costs.

Each decade since the 1930s has seen more than a tenfold increase in the energy of the particles produced by accelerators: from cyclotrons with a few million electron volts (MeV) of energy in the mid-thirties to today's huge Tevatron at Fermilab, the U.S. national accelerator laboratory in Illinois, with its beam of 1 TeV (one trillion electron volts).

An important development in the progression was the discovery of the principle of strong focusing in the early 1950s. Strong focusing systems in particle accelerators consist of a series of magnets, one strongly focusing the particles horizontally but defocusing them vertically, followed by another that does the opposite. It was discovered that this sequence of alternating magnets has the remarkable property of strongly focusing and constraining the transverse size of the particle beams. As a result, beam pipes could be made much smaller, as could the magnets that surround them. The cost per unit length of synchrotrons was significantly reduced, thus making larger machines economical. A later, simplifying development for the larger machines was the introduction of "separate function magnets," dipole magnets to provide the necessary bending of the orbits, and quadrupole magnets to accomplish the strong focusing.

To understand the interplay of particle energy, magnetic field strength, and circumference of an accelerator, it is useful to take note of the following relation. The bending radius, R, in kilometers is related to the energy, E, in TeV (technically, the momentum times the speed of light) and the magnetic field, B, in teslas according to

$$R\ (\mathrm{km}) = \frac{10\ E\ (\mathrm{TeV})}{3\ B\ (\mathrm{tesla})}$$

The higher the magnetic field, the smaller the bending radius for a given energy. For a circular ring, the minimum circumference is $C = 2\pi R$. In practice, the separation of functions of bending and focusing, and the presence of straight sections without magnets causes the circumference to be 25 to 50% larger than the minimum value. One example, to be discussed later, has B = 6 tesla, E = 20 TeV, leading to a bending radius, R, of 11 km. However, the design circumference is 96 km (60 miles), roughly 40% larger than the calculated ($2\pi R$) circumference of 69 km.

During the the late sixties and the seventies, the most significant advance in accelerator technology was the development of techniques leading to head-on collisions between two beams of particles— in contrast to the older method of aiming a single accelerated beam at a stationary target. In collisions with a stationary target, much of the energy of the incident particle is expended in causing itself and its collision partner to move forward at high speed. Relatively little energy is left for interesting effects such as new particle production. Head-on collisions permit utilization of all of the energy of the two beams for research purposes. For example, it would take a fixed target machine with a beam energy of 2000 TeV (with a circumference of 8000 miles!) to equal the useful energy available in a head-on collision between two protons that have been accelerated to 1 TeV (in a circumference of 4 miles). Because of such advances in accelerator technology, the energy range that is accessible to scientists has increased more than a millionfold in the past 50 years, while the cost per electron volt of beam energy has decreased dramatically during the same period.

Machines in which head-on collisions occur are known as "colliders." A collider is usually designed as a "storage ring," in which particles can be collected, accelerated, and stored. If the colliding particles are protons, they can be stored for as long as several days while repeated collisions take place. The colliders and storage rings that have been built so far have all been configured as circles or ovals. They range in size from a few feet in circumference to 4 miles for the largest now in existence, the collider at CERN in Geneva, Switzerland with 0.3-TeV beams and the soon-to-be-operational Tevatron collider at

Fermilab, with its 1-TeV beams.

The significance of the Tevatron is greater than might be inferred merely from the fact that as a collider it will soon provide collisions with three times the energy of the CERN machine. Operating since late 1983 in a fixed target mode, the Tevatron is the world's first large accelerator to exploit superconducting magnet technology. The addition of roughly 1000 superconducting dipoles and quadrupoles in the existing tunnel has permitted a two-fold increase of the energy of the machine with no increase in size. Superconducting magnets are doubly advantageous, providing greater maximum magnetic field strengths coupled with small electrical power requirements. The feasibility of the SSC depends in part on these proven qualities. It will be the largest collider and storage ring in the world, with an energy of up to 20 TeV in each beam particle, or a total useful collision energy of 40 TeV.

While the discussion so far has stressed the final energy of the beams and the accompanying ring of magnets of very large circumference, there is an elaborate sequence of operations before the accelerated particles enter the final ring. It is technically very difficult at high energies to increase the energy of a proton by more than a factor of ten or twenty in any given configuration of magnets. The reason can be seen in the relation stated above among the magnetic field, B, the energy, E, and the bending radius, R. For a fixed radius, as in a synchrotron, the energy and field are kept in proportion. Protons injected at a low energy must start in a low field. As the radiofrequency electric fields cause them to gain energy, the magnetic field must be increased in unison. However, for a given set of magnets, there are limits to the extent of possible variation of the field while maintaining the required field quality. It is therefore necessary to have a cascade of accelerators, each more powerful than the preceding one. The protons start on their journey with a modest beginning, are accelerated part way, then transferred to the next machine, and so on to their ultimate destination, the collider ring. At Fermilab, for example, there are four major elements in the sequence, a linear accelerator that accelerates the protons to a kinetic energy of 0.2 GeV (1 GeV = 1 billion electron volts), then a rapid-cycling booster that brings their energies up to 8 GeV. From the booster, the protons are injected into a main ring of conventional magnets where they are accelerated to 150 GeV (0.15 TeV) before transfer to the superconducting ring for a boost to the final energy of 1 TeV. One possible cascade of accelerators for the SSC is shown in Figs. 1-2 and 1-3. The part of the cascade up to the collider ring is usually called the injector, even though each member of the cascade is an accelerator in its own right.

B. DESCRIPTION OF THE SSC

The proposed SSC as described in the Reference Designs Study (RDS) consists of four basic components: 1) an injector complex of three cascaded accelerators roughly similar to Fermilab's Tevatron, in which protons will be accelerated from rest to about 1 TeV; 2) the collider ring, whose circumference will be between 60 and 100 miles, depending on the final magnet type selected; 3) the experimental areas; and 4) the campus/laboratory area. This section describes these components in greater detail.

1. The Injector Facility

As already described, machines like the SSC require a cascade of accelerators. In the model of the RDS, the injector consists of a cascade of three separate accelerators, a linac, a low-energy booster, and a high-energy booster, each accelerating the protons to ever higher energies while maintaining their bunched beam structure. Components of the injection system will be buried at least 20 feet underground and in the RDS were located close to the campus-laboratory area. Two prime performance objectives apply to the SSC injector: 1) its beam must have a concentrated high flux of protons to achieve the specified beam intensity in the collider ring; and 2) its final energy must match the lowest energy permitted by the magnetic field of the collider ring in order to prevent beam loss at injection.

The first step of the injection system is a linear accelerator (linac) in which the protons are generated in an ion source and accelerated from rest to energies as high as 1 GeV. The linac would be approximately 750 feet long and consist of many radio-frequency (rf) cavities in line. From such a linac, the protons are transported through a beam pipe into a low-energy booster (LEB). In the RDS, the LEB is designed to raise their energy to 70 GeV. Such a synchrotron would be about 0.7 miles in circumference, and would utilize conventional magnets.

From a 70-GeV LEB synchrotron, the last step of the injection process would be a high-energy booster (HEB), in which the protons have their energy raised to approximately 1 TeV, the minimum energy necessary for injection into the collider ring. The high energy booster is itself an accelerator of impressive proportions, approximately 4 miles in circumference. It would use superconducting magnets cooled by liquid helium in a system similar to the operating Tevatron at Fermilab.

The conventional facilities of the injector complex include an enclosure for the linac, an LEB tunnel roughly 0.7 mile in circumference, with six power supply junctions, one injection and two extraction sections. The HEB tunnel is about 4 miles in circumference with six power-supply buildings, one building for the refrigeration system, two injection areas, one rf area, and two extraction/abort areas. Figure 1-3 shows an arrangement of the injector complex and the collider ring, and Fig. 1-4 is an aerial perspective of a possible site layout.

2. The Collider Ring

The most prominent single element of the SSC is the collider ring, a circular tunnel whose cross-section has a diameter of about 9 feet and a circumference (depending on the final design chosen) from 60 to 100 miles. Inside the tunnel are two rings of superconducting bending (dipole) and focusing (quadrupole) magnets, which steer and confine two beams along approximately circular orbits. The bunches of 1-TeV protons received from the high energy booster are apportioned between the two collider rings and accelerated in opposite directions. For most of the circumference, the two beams travel in separate, parallel vacuum chambers, side by side or one above the other. At six locations the counter-rotating beams, having been focused to less than one thousandth of an inch in transverse dimensions, are brought into collision. The two beams are directed to collide almost head-on in the heart of the particle detectors, which surround the beams at the interaction points.

As discussed in the introduction, the circumference of the collider ring of the SSC will depend on the strength of the dipole magnets chosen to bend the trajectory of the protons. A tunnel of 60 miles in circumference would be required with the stronger magnets (about 6 tesla [T], or 60 kilogauss). An even larger circumference, 100 miles, would be needed if lower field (3-tesla) magnets are chosen. The decision, expected by the end of September 1985, about the kind of magnets to be used in the final design of the SSC will be based on the results of development efforts now in progress at several accelerator laboratories around the country.

Despite their differences in circumference, the alternative collider ring designs share certain basic features. For example, a specific ring design might be planned as a circle (actually, a combination of short straight sections and arcs approximating a circle) but might also be conceived as a racetrack shape if the chosen site proves more suitable for that type of configuration. The six regions at which the beams intersect may be widely and symmetrically spaced around the ring, or they may be grouped at two or three regions. In the most convenient accelerator designs the collider ring lies in a plane. The plane can be horizontal or tilted slightly (not more than one degree) to accommodate a slope on the site.

Basic to the SSC, whatever its size, are the existence of six experimental regions containing straight sections where beams collide and experiments take place. In addition, there are special utility regions for beam injection, beam extraction and abort, and the radiofrequency acceleration systems.

In addition to the technical components of the SSC accelerator itself, the project will contain a number of structures and facilities that involve conventional design and construction techniques. For example, in one of the designs of the RDS, twelve buildings, equally spaced around the collider ring, would house the services needed for the power supplies and refrigerators. Additional buildings would be provided for injection/extraction and for rf equipment.

3. The Experimental Areas

The experimental areas will be designed to be at six interaction regions around the collider ring circumference. At each developed area, enclosures will be provided at beam level and support buildings at the surface. At the beam level are the collision hall and the access hall enclosures. A typical collision hall with a height of 50 feet is envisioned to provide a central gallery approximately 70 ft by 70 ft, with a 45 ft by 45 ft gallery at each end along the beam direction. In detailed design each hall may be different in order to adapt it to the local site condition and to its intended use. A tunnel by-passing the experimental area makes it possible to detour equipment around the collision hall and to convey the tunnel services.

A subterranean access hall at each experimental area will provide assembly areas. Because of the enormous weight of individual detector components and their number, a relatively thick floor with steel plate might be used as the common floor for the collision and access halls.

A staging building above the access hall will provide space for the experimental teams to make a sub-assembly of their experimental apparatus and to maintain their equipment. A 300 ft by 120 ft building would contain workshops, offices, a light-duty laboratory, and counting rooms. An overhead crane in the staging hall would permit work at either the staging level or the access hall below.

4. The Campus Area

The campus complex may consist of fifteen or more buildings clustered in four major groups -- central laboratory buildings, industrial buildings, warehouses, and auxiliary support buildings.

Central laboratory buildings provide office and laboratory space for administrative and technical personnel. One building might contain all of the major offices of the facility and light laboratories for the development and testing of electronic components. It would also include control rooms, an auditorium, computing facilities, a main cafeteria, a series of conference rooms, and a small infirmary for emergency medical needs. Figure 1-5 is a conceptual rendering of such a building.

Industrial buildings will house limited component assembly activities and associated offices. Warehouses serve as receiving and storage facilities. The auxiliary support buildings -- fire, site patrol, rescue and vehicle storage buildings provide services to the entire complex.

C. ESTIMATED COST AND SCHEDULE

It is expected that the actual construction of the SSC could be accomplished in about six years, which would mean completion in early 1994 if construction were to begin late in 1987. In the RDS, the cost for the construction of the accelerator facilities was estimated to be from $2.7 to $3.1 billion (FY 1984 dollars), depending on the magnet design chosen. The conventional construction represents approximately one-third of this cost. The total cost including the preconstruction R & D, the cost of the detectors, and other pre-operating costs for the facility, is about $4 billion (FY 1984 dollars). Savings on technical components may come about through optimization of designs, economy of scale in production, and improved techniques of magnet manufacture.

Site characteristics will have a direct influence on underground construction, which represents the largest single element of the conventional facilities cost. Choice of a site amenable to rapid tunneling techniques is desirable because it will contribute significantly to cost and schedule optimization. Additional site-related construction elements that will affect cost and schedule are the availability of:

- The site itself;

- Existing structures and access roads;
- Adequate utilities;
- Construction materials and labor.

D. ENVIRONMENTAL IMPACT AND RADIATION SAFETY

It is intended that the environmental impact of the SSC upon its site be minimal. As already discussed in the Introduction, apart from the occasional cluster of buildings above the ring and the larger concentrations at the injector and the separated interactions regions, the landscape will show negligible signs of the working accelerator below ground. The collider tunnel will be buried sufficiently deep to contain the small amount of stray radiation that is produced by machines of this sort. Just as at SLAC in California, DESY in Germany, Fermilab in Illinois, or CERN in Switzerland, the local population will live in complete harmony and safety with the laboratory. Even in the immediate neighborhood of the SSC, the radiation exposure will be quite small compared to that occurring from cosmic rays and other natural backgrounds, and will be below the minimum values set by appropriate agencies. During operation, protons traveling in the evacuated beam pipe produce no radiation that leaves the tunnel. The primary source of radiation will come from the particle interactions being studied in detectors at the interaction regions. Most such radiation will be absorbed internally by the detectors and will not even reach the walls of the tunnel, much less get to the surface.

In the event of a malfunction of the accelerator or a natural occurrence such as an earthquake, the beam would be promptly extracted and absorbed in a specially-prepared isolated area. In the unlikely event that the beam was accidentally lost somewhere around the ring, the momentary radiation appearing outside the earth shield would be small. After such a loss of beam, the remaining particles would be promptly removed from the SSC and produce no more radiation.

It should be emphasized that the operation of a particle accelerators is very different from that of nuclear fission reactors. An accelerator contains essentially no inherent source of radioactivity that could be released accidentally. The source of energy to accelerate particles is obtained from the same commercial electrical power grid that one taps for household appliances. Just as when an electric toaster is unplugged there is no long-term fire hazard from it, so when the SSC is off there is no potential for creation of new radiation. Like any accelerator, the SSC has within its shield some short-lived residual radiation coming from unstable nuclei created in the process of containment of the primary and secondary particles. This low-specific-activity radiation is confined to the tunnel walls and the earth in the immediate vicinity of the tunnel. It decays rapidly and causes no hazard to anything on the surface.

E. RECENT CHRONOLOGY OF THE PROJECT

Summer 1982: Summer study of the American Physical Society's Division of Particles and Fields, was held at Snowmass, Colorado. An in-depth examination of the idea of a 20-TeV/beam proton-proton collider resulted from this meeting. Strong widespread support for the physics goals of such a collider emerged.

February 1983: A week-long workshop was held at the Lawrence Berkeley Laboratory (LBL) in California to consider detector problems for a high energy, high luminosity hadron-hadron collider.

March 1983: A workshop was held at Cornell University in Ithaca, N.Y., to consider technical and cost questions associated with construction of a 20-TeV/beam hadron-hadron collider.

July 1983: A subpanel of the High Energy Physics Advisory Panel (HEPAP), convened early in 1983 to consider the future high energy facilities in the United States, recommended construction of a new high energy, high luminosity, hadron collider. This recommendation, unanimously endorsed by HEPAP as its "highest priority" for high-energy physics, was transmitted to DOE.

Fall 1983: DOE initiated preliminary R & D for the SSC. Hearings were held before the House Science and Technology Committee concerning redirecting resources toward the SSC R & D.

December 1983: The Reference Designs Study was chartered by the directors of the U.S. high-energy accelerator laboratories with the energy and luminosity goals defined.

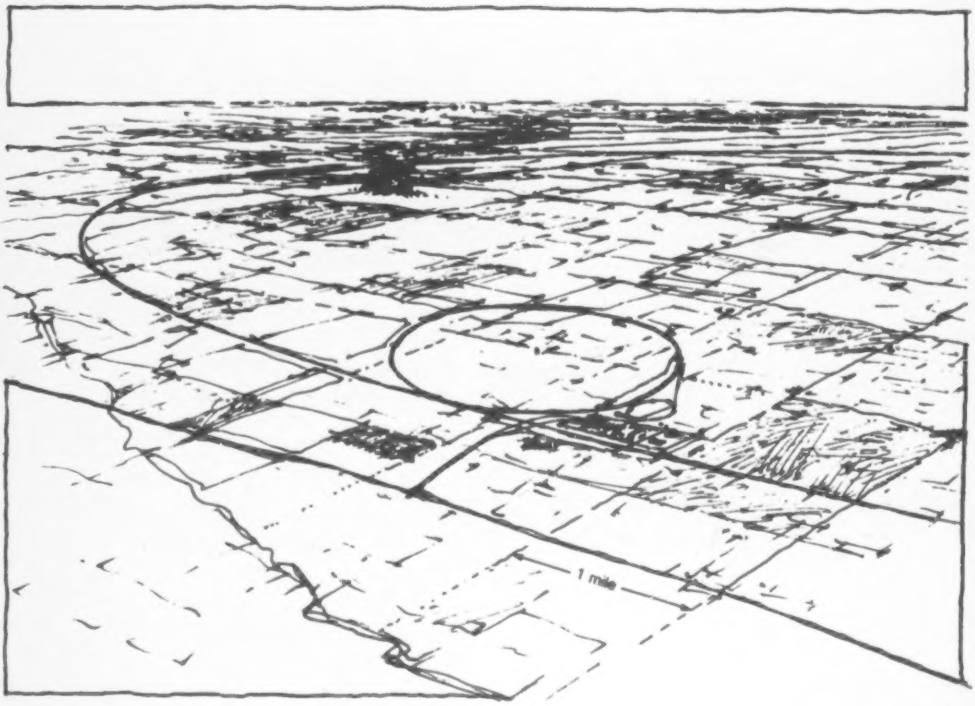
March 1984: DOE assigned responsibility for oversight of the national SSC effort during the R & D preconstruction phase to the Universities Research Association.

Spring 1984: The Reference Designs Study was held at LBL with about 150 participants. It was concluded that a 20 TeV on 20 TeV proton-proton collider is technically feasible. The Study, also containing construction cost estimates and schedules, was extensively reviewed by DOE personnel and their consultants.

Summer 1984: Initiation of the Phase I R & D program for the SSC was approved by the Secretary of Energy. Extensive work on model magnets for the SSC was already underway at Brookhaven National Laboratory, Fermilab, Lawrence Berkeley Laboratory, and the Texas Accelerator Center.

Fall 1984: Formation of the Central Design Group (CDG), headquartered at the Lawrence Berkeley Laboratory. The CDG has been charged with directing and coordinating all of the SSC R & D work nationwide.

Spring 1985: SSC Siting Parameters Document submitted to the Department of Energy.



XBL 853-9782

Fig. 1-1.

Aerial view of median site illustrating the scale (see 1-mile marking) of the SSC facility. The collider ring perimeter is only noticeable when the tunnel approaches the surface. The injector and campus area are visible in the center. Access roads to nearby population centers are clearly visible.

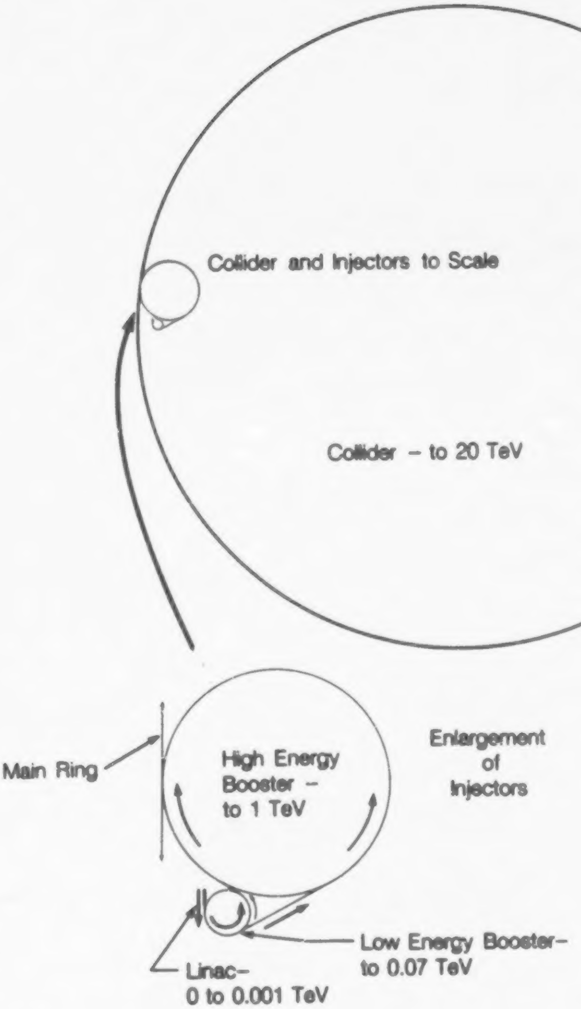

Collider and Injectors to Scale
Collider – to 20 TeV
Main Ring
High Energy Booster – to 1 TeV
Enlargement of Injectors
Low Energy Booster– to 0.07 TeV
Linac– 0 to 0.001 TeV

Fig. 1-2.

Layout of the SSC indicating the injector complex and the collider ring where protons are accelerated to 20 TeV in counter-rotating bunches that collide at six points around the circumference.

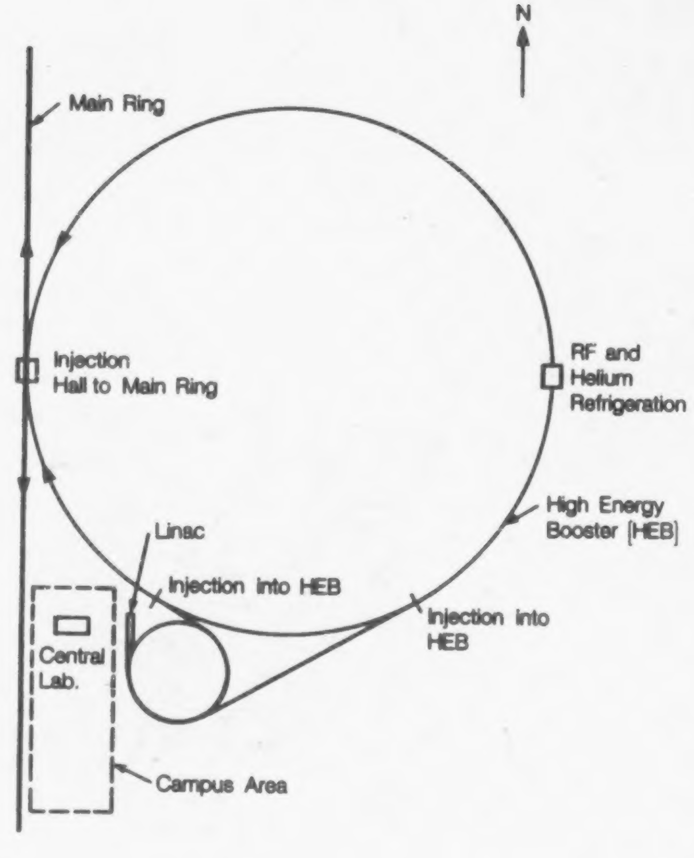

N
Main Ring
Injection
Hall to Main Ring
RF and
Helium
Refrigeration
High Energy
Booster [HEB]
Linac
Injection into HEB
Injection into
HEB
Central
Lab.
Campus Area

Fig. 1-3.

Arrangement of the injector complex adjacent to the collider ring, as depicted in the Reference Designs Study.

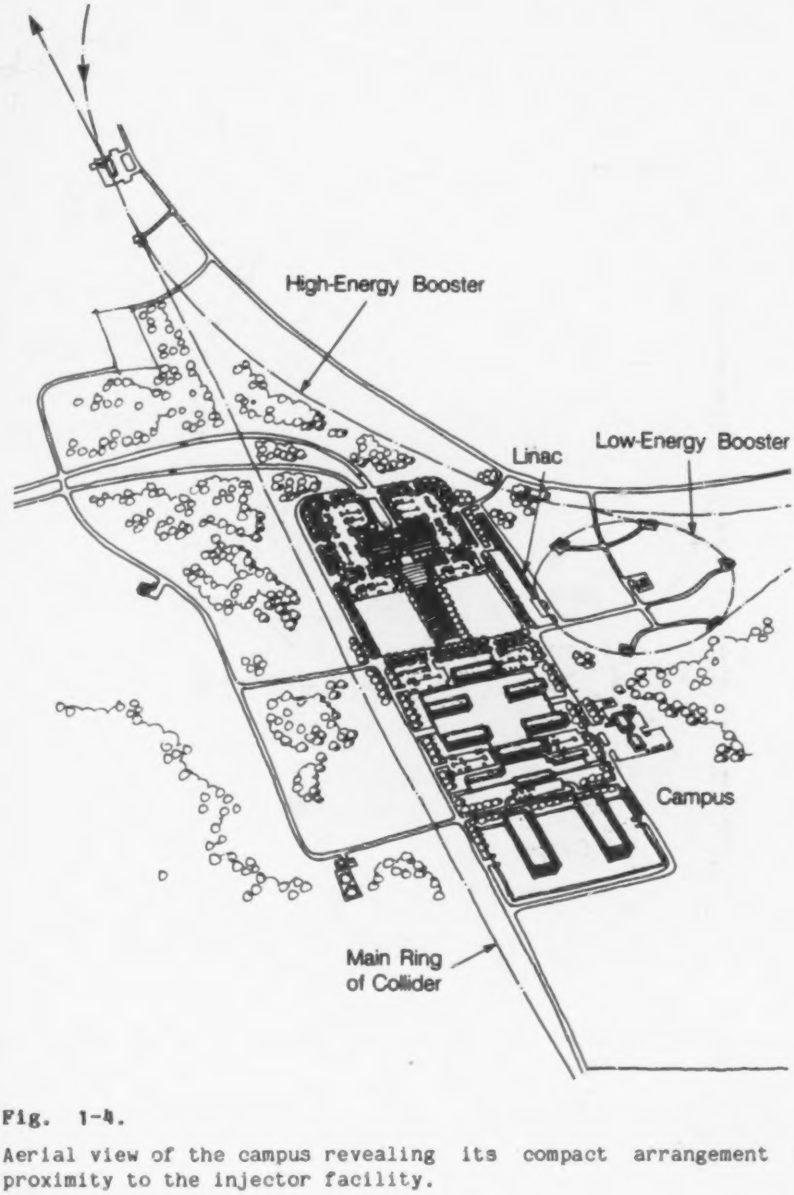

High-Energy Booster
Linac
Low-Energy Booster
Campus
Main Ring
of Collider

Fig. 1-4.

Aerial view of the campus revealing its compact arrangement and its proximity to the injector facility.

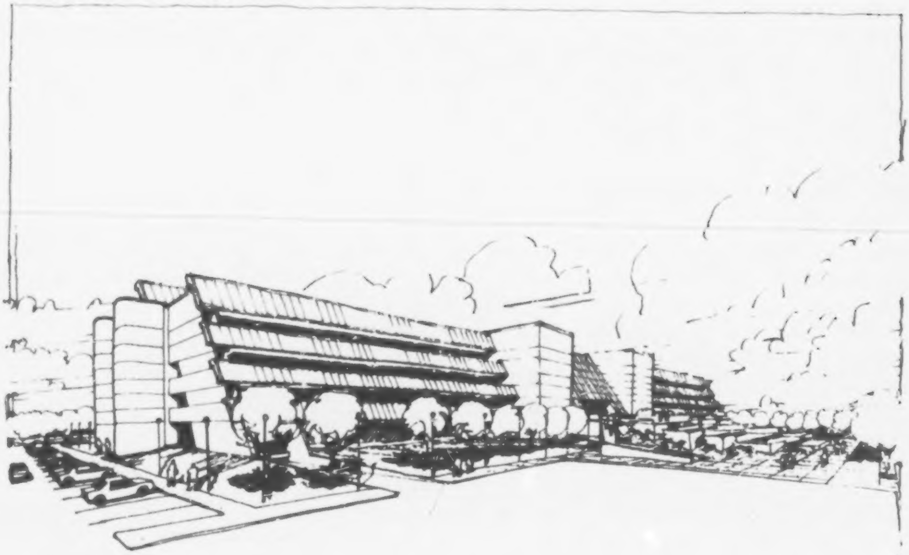


Fig. 1-5.

The south facade of the central laboratory building as envisioned in the Reference Designs Study.

PART II. FEATURES OF THE SSC FACILITY

This chapter summarizes requirements envisioned for the proposed SSC facility. The information used is derived from the Reference Designs Study (RDS) with attention given to the two magnetic field strengths for the bending magnets currently being considered. After a brief description of the scope of the collider ring, the main technical features of the RDS accelerator and laboratory facilities are enumerated. These features lead to the tables of facility parameters, one set for 6-tesla magnetic field, the other for 3-tesla. Because the parameters are derived from the particular models used for the RDS, they should be considered only approximate, illustrative of one possible class of designs. Although a detailed design for the SSC has not been completed, it is believed that the physical requirements will not change significantly once a magnetic field strength is chosen.

A. CONSTRUCTION FEATURES

The overall scale of the SSC Laboratory is determined by the energy chosen for the collider beams and the magnetic field strength of the magnets for the ring. The design energy is 20 TeV. For the two types of bending magnets under consideration, 6 T and 3 T, approximately circular rings of 60 and 100 miles circumference would result. The cross-section of the tunnel enclosing the collider rings will be about 9 feet in diameter, determined by the need to install, operate, and maintain the magnets and associated equipment.

Radiation shielding for the collider requires 20 feet of earth around the tunnel. In addition, particles (muons) that are produced tangentially (i.e., toward the outside of the ring) must be attenuated. Absorption of these particles requires that a corridor be reserved adjacent to, and radially outside the shield, including space 25 feet above and below the plane of the accelerator. Wells and other penetrations can exist within this corridor but sustained human occupancy would not be permissible. The overall width of the radiation zone is 700 feet in the 6-T configuration, and 350 feet in the 3-T case, as shown in Fig. 2-1.

Access to the tunnel and structures for equipment will be provided at various locations around the perimeter. Twelve major service areas are provided for refrigerators, power supplies, and access shafts in the 6-T case, and twenty four in the 3-T case, uniformly distributed around the ring. The service locations require power for the helium compressors, power supplies, and the nitrogen liquefaction systems. Sufficient industrial cooling water to reject the heat from the compressors and the air-conditioning associated with the technical systems must be available. Land area must be provided on the surface at each of the service locations for a building or buildings to house the technical systems, along with space for maintenance purposes. A storage yard for helium and nitrogen gases must also be provided. The total area requirement at each of these locations is approximately 30 acres. Between these locations additional shafts are provided that serve for tunnel ventilation and also provide emergency exit. The total area needed for both the service areas described above and the necessary infrastructure such as roads, utility and communication runs is about 800 acres for the 6-T case and 1500 acres for the 3-T case.

In the RDS, three designated locations around the collider ring provide facilities for injecting beams clockwise and counterclockwise into the machine, for accelerating the beams, and for ejecting the beams from the machine. At each of these locations, an area of approximately 10 acres will be required to house the associated equipment. An ejected beam at an abort location will travel in a tunnel tangential to the ring for approximately 0.6 miles before being absorbed in a shielded beam dump. Like the ring tunnel, the abort tunnel must have a cover of 20 feet of earth. An area of approximately 80 acres beyond the dumps encompassing a width of 50 feet on either side of the beam dump axis for a distance of approximately 3 miles must be provided.

At six locations around the ring large experimental halls are provided, each accompanied by extensive support facilities. These six areas may be spaced equidistantly around the perimeter or clustered in groups of two or three. For a design with clustered experimental areas the perimeter takes a shape that is more oval or in another case, slightly triangular, rather than circular. The experimental areas will each require approximately 60 acres of land, which will include an assembly and control building for the detector, machine shops, food services facilities, parking, space for expansion, etc. The power requirements and industrial and low-conductivity water requirements at the experimental areas will be approximately the same as for the refrigerator/power supply areas.

The campus area and the central laboratory building will be the primary focal point for work at the SSC. It is expected that about 500 acres of land will be needed to accommodate the 3000 people who will use the campus. Also in the campus area are the injector facilities. This will be a group of accelerators used to boost the beam to sufficient energy to be injected into the collider ring. In the RDS, the injector consisted of a linear accelerator (linac), and two circular booster accelerators. These are substantial accelerators in their own right, and altogether require a space of about 1500 acres.

B. TABLE OF TECHNICAL FEATURES OF THE SSC

The major technical features of the SSC Reference Design are as follows:

Injector

Linac	
Energy	1 GeV
Length	750 ft

Low-Energy Booster	
Energy	70 GeV
Circumference	0.7 mi
Conventional Magnet Peak Field	2 T
No. of Service Buildings	6

High-Energy Booster	
Energy	1 TeV
Circumference	4 mi
Superconducting Magnet Peak Field	5 T
No. of Power-Supply Service Buildings	6
No. of Helium Refrigerators	1
No. of RF System Service Buildings	1

Collider

Peak Bending Field	**6 T**	**3 T**
Beam Energy	20 TeV	20 TeV
Accelerator Circumference	60 mi	100 mi
No. of Counter Rotating Beams	2	2
No. of Power-Supply Service Buildings	12	24
No. of Helium Refrigerator Systems	12	24
No. of Nitrogen Liquefier Systems	2	4
No. of Injection Conjunctions	2	2
No. of RF Accelerating Systems	2	2
No. of Abort Systems	2	2

Experimental

No. of Interaction Regions (equally spaced, or clustered in two or three areas)	6	6

C. TABLE OF FACILITY PARAMETERS FOR THE SSC USING 6-T MAGNETS

This table summarizes the basic physical parameters of the SSC for the 6-T peak bending field configuration. The requirements are derived from the RDS.

1. General

Magnetic Field	6 T
Circumference of the Collider Ring	60 mi

2. Area

Campus	500 acres
Service Areas	400
Site Infrastructure	400
Injector	1,500
Collider	5,000
Experimental Areas	500
Total	8,300 acres

3. Above-Ground Buildings (gross area)

Campus Buildings		
Central Laboratory Building	365,000 sq ft	
6 Assembly Buildings	168,000	
3 Shops Buildings	30,000	
2 Warehouses	80,000	
Other Buildings	24,000	
Subtotals		667,000 sq ft
Injector Service Buildings		56,000
Collider Service Buildings		112,000
Experimental Area Buildings		225,000
Total		1,060,000 sq ft

4. Below-Ground Enclosures

Injector	28,000 ln ft
Collider (excluding experimental areas)	317,800
Experimental Areas	2,200
Total	348,000 ln ft

5. Utilities (average except as noted)

Average Electric Power Demand	106 MW
Peak Electric Power Demand	160 MW
Heat Rejection Load	306 MBtu/hr
Cooling-Tower Make-Up Water	780 gal/min
Potable Water	310 gal/min
Pond Make-Up Water	130 gal/min
Irrigation Water	300 gal/min
Fire-Protection Water Storage	2.8 Mgal
Sewage-Plant Effluent Discharge	91,000 gal/day
Solid-Waste Disposal	30,000 cu yd/yr
Heating Rate (coldest month)	55,000 MBtu/hr
Telecommunications	200 trunks

D. TABLE OF FACILITY PARAMETERS FOR THE SSC USING 3-T MAGNETS

This table summarizes the basic physical parameters of the SSC for the 3-T peak bending field configuration. The requirements are derived from the RDS.

1. General

Magnetic Field	3 T
Circumference of the Collider Ring	100 mi

2. Area

Campus	500 acres
Service Areas	800
Site Infrastructure	700
Injector	1,500
Collider	4,300
Experimental Areas	500
Total	8,300 acres

3. Above-Ground Buildings (gross area)

Campus Buildings		
Central Laboratory Building	365,000 sq ft	
6 Assembly Buildings	168,000	
3 Shops Buildings	30,000	
2 Warehouses	80,000	
Other Buildings	24,000	
Subtotals		667,000 sq ft
Injector Service Buildings		56,000
Collider Service Buildings		169,000
Experimental Service Buildings		225,000
Total		1,117,000 sq ft

4. Below-Ground Enclosures

Injector	28,000 ln ft
Collider (excluding experimental areas)	525,800
Experimental Areas	2,200
Total	556,000 ln ft

5. Utilities (average except as noted)

Average Electric Power Demand	117 MW
Peak Electric Power Demand	196 MW
Heat Rejection Load	303 MBtu/hr
Cooling-Tower Make-Up Water	775 gal/min
Potable Water	310 gal/min
Pond Make-Up Water	130 gal/min
Irrigation Water	300 gal/min
Fire-Protection Water Storage	2.8 Mgal
Sewage-Plant Effluent Discharge	91,000 gal/day
Solid-Waste Disposal	30,000 cu yd/yr
Heating Rate (coldest month)	55,000 MBtu/hr
Telecommunications	200 trunks

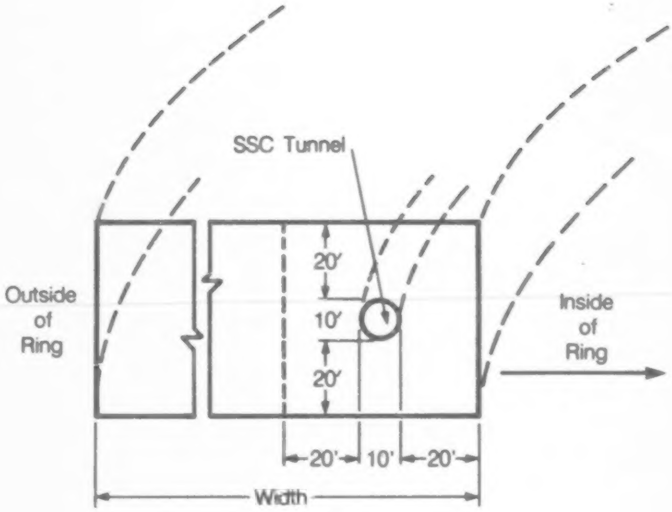

SSC Tunnel
Outside of Ring
Inside of Ring
20'
10'
20'
20'
10'
20'
Width

Fig 2-1.

This drawing illustrates the volume of space and the tunne that must be under SSC control. The width is 700 feet f the 6-T configuration and 350 feet in the 3-T case.

PART III. SSC SITING CRITERIA

Earlier parts of this document have described the proposed SSC, its basic physics parameters, technical and construction features. Part II, in particular, quantifies the major SSC parameters that form the basis for the siting criteria described below. These siting criteria have been developed to assist in the process of site identification. The criteria were derived after thorough examination of desirable site characteristics as developed during the preparation of Part IV.

The quantitative siting criteria used herein differ from the Part II parameters in that values have been augmented to reflect possible alternate design configurations, and to provide flexibility for adaptation of the SSC to a specific site.

A. SETTING

The scale of the SSC is its most notable physical feature. In the region where it will be located, an overall area up to 40 by 50 miles would be influenced by the presence of the SSC. It is envisioned that the collider ring will be configured on a plane. Consequently a desirable topography of the proposed siting area would be generally flat or gently sloping to minimize shaft depth and permit the collider tunnel to be built on a horizontal plane, or one tilted up to 1 degree.

Independent of the two tunnel circumferences being considered, the whole SSC complex will occupy about 11,000 acres (17 square miles) appropriately distributed around the perimeter of the collider in a manner similar to that of the examples in Part II. Permanent and exclusive SSC use (fee simple) will be required for about 5000 acres for the campus, service areas, injector area, and experimental areas. This includes at least 1700 acres providing an allowance for SSC adaptation to the site, laboratory growth, and possible future external beam lines for experiments or injection into other research devices.

With respect to the collider, in areas where the tunnel is buried much more than 20 feet underground and where there are no SSC surface buildings over the tunnel, land could be shared with others with priority of use (by easements) granted to the SSC. To maintain the integrity of the tunnel and SSC operations, a volume of below-ground space around the tunnel must be under SSC control. This volume was described in Part II and shown in Fig. 2-1. This configuration leads to a horizontal projected area at the surface of about 5000 acres. In addition, right of way easements for roads, utility and communications runs will bring the total up to 6000 acres. For a shallow very flat site, all the SSC tunnels would be constructed by cut and fill methods. This would require that permanent and exclusive use (fee simple) be granted to the SSC for all segments of the project, leading to a requirement for the entire 11,000 acres.

The band of land totalling up to 17 square miles would encircle a large area of several hundred square miles that would be unaffected, allowing continued use and habitation. The SSC will be planned, designed, constructed, and operated as a Federal installation. It will be important to know the cost of land acquisition, if any, to the Federal Government, and the value of any donations of land and services that may be offered.

The size of the collider may cause it to pass through several local jurisdictions. The successful construction and safe operation of the facility require that provision be included, through enabling legislation, if necessary, for the SSC to be built and operated under a single, uniform set of codes and health, safety, and environmental rules.

B. ENVIRONMENT

The proposed site should be such that the SSC facility can be positioned, constructed, and operated in an environmentally acceptable way. The Department of Energy (DOE) will comply with the requirements of the National Environmental Policy Act (NEPA) and will prepare an Environmental Impact Statement (EIS) that will include an analysis of the impacts of construction and operation of the SSC. Environmental characterization information provided by a proposer would be used by DOE in preparing an environmental evaluation. Because the environmental characterization data contained in proposals might be used by DOE in preparing a full EIS, proposers should be encouraged to submit the best data available; four seasons of monitoring data are highly desirable.

C. GEOLOGY AND TUNNELING

Because major portions of the SSC will be built underground, the cost and efficiency of underground construction and tunneling are important considerations in selecting the site. For construction purposes, relatively uniform geological characteristics are desirable to permit large contiguous segments to be built using a common construction methodology. For example, if a tunnel in rock is proposed, rock with few fractures or discontinuities and sufficient compressive strength to permit unsupported tunneling would be most desirable. Structural features such as faults, shear zones, buried valleys, and deep or shallow subsidences are to be avoided to the maximum extent possible. In areas where cut-and-fill construction or embankments are proposed, conditions that could result in settlements and ground movements, including slope failures, should be avoided. Soft soils, such as certain clays, present difficult tunneling, excavation, and foundation conditions and should be avoided. Bearing capacity for foundations in the experimental areas (halls) should be sufficient to minimize differential settlement between halls and the adjacent tunnels. Typical floor loadings in the experimental areas are estimated as 6 tons per sq ft with total loads of up to 10,000 tons. Elsewhere loading is light, less than that exerted by the removed material.

Ground water may pose significant underground construction problems in pervious soils or where rock tunnels traverse water-bearing faults or shear zones. As a practical matter, tunnel construction in unconsolidated granular soils containing ground water with a head greater than about 100 feet is very difficult and should be avoided to the maximum extent possible. Local pervious structural features in rock can usually be stabilized, but tunneling through great lengths of pervious material would be time consuming and costly.

Properly designed underground facilities are generally insensitive to seismic effects. In a seismically active area provisions are required in the design of certain surface structures, of underground experimental halls, and by the provision of restraints for installed underground equipment (magnets, cryogenic system, experimental detectors, etc.). A seismic event involving rupture along a fault crossing any portion of the facility cannot be mitigated, and thus a site crossing an active fault is unacceptable.

D. COMMUNITY RESOURCES

Communities near the proposed site should be sufficiently large to support up to 10,000 people (3000 staff and visitors and their families) attracted by the construction and operation of the proposed SSC. Although it is anticipated that a large percentage of Laboratory employees will be drawn from adjacent communities, a substantial number of new families must be drawn from elsewhere to work at the new SSC laboratory. They will require suitable housing, schools, shopping, and related facilities. A significant growth of established and new communities may be required. Furthermore, temporary or transient quarters, such as hotels, motels, and apartments will be needed to accommodate a large number of visitors, including scientists, government officials, and others participating in the activities of the laboratory. It is thus desirable that the laboratory facilities should be within a reasonable commuting time of existing or potential communities.

A major airport facility, supported by public transportation, rental cars, and related services, should be readily accessible to the Laboratory. The existing or projected regional transportation network should have the capacity to serve the SSC needs. Ready access to the entire laboratory facility from local communities and from outside the region is essential. Interstate-quality highways and all-weather roads for public and private transportation capable of carrying major construction loads as well as commuter traffic to and from the laboratory will be expected to exist or be provided.

Nearby educational facilities will also be important. Good quality primary and secondary schools will be essential for the families of the staff. Universities, colleges, and institutes in the area could contribute to its desirability by providing a source of technical staff and opportunities for continuing education for the staff.

To attract the needed scientific staff, the surrounding area should offer sufficient quality and quantity of social and cultural opportunities. Recreational resources within the region are valuable in making the nearby communities desirable.

For economy it is desirable that industrial and construction resources be drawn from the surrounding communities whenever possible.

E. UTILITIES

Water availability is a significant consideration in evaluating site suitability. A potential need for up to 2000 gal/min of water exists, of which 500 must be potable. For industrial purposes the quantity and quality of water available will dictate the type of cooling system to be provided, which in turn will affect the associated power demand and the facility operating cost. The required industrial water flow rate that would permit the most efficient use of electrical power is about 1500 gal/min. The lack of water would increase the power demand significantly. Sites capable of supplying as little as 500 gal/min. of industrial water can be considered but will require the use of about 25% more power for forced-air cooling.

The amount of electrical power required to support the operation of the SSC will depend on the type of cooling system used. As noted above, sites with abundant available cooling water will require less electric power than will those with limited amounts of available water. The peak power requirement for the SSC, based on desirable climatic conditions and on the use of a typical industrial-water evaporative cooling system, will be about 200 MW. If an air-cooled system is used, the peak electrical power demand for the SSC site is anticipated to be about 250 MW.

High stability and reliability of the electrical grid serving the SSC is essential. Generating capacity should be at least 12 times rated peak site load. It is highly desirable that power be provided by two separately routed feeder lines each connected to different points on the grid(s) such that essential loads are maintained in the event either line is out of service. Long power outages (more than 30 minutes duration) will result in a significant expense through loss of cryogenic fluids from the magnets. Outages of a few seconds or less can cause significant interruptions to the laboratory program. More than two unanticipated outages per independent feed per year on the average would have a considerable negative impact on maintaining machine operations.

A fuel supply compatible with the climate is necessary. For example, a local fuel-delivery system capable of providing at least 60,000 MBtu/hr should be available to serve the laboratory if the coldest month at the site corresponds to 900 degree-days.

F. MAN-MADE DISTURBANCES

Because colliding-beam research depends upon two small beams accurately hitting each other head-on for many hours, stability of operation is important. Sources of noise or vibration such as those produced by airplanes, highway and railroad traffic, or industrial activities could be disruptive and must be examined.

The beams are sensitive to ground motion in the frequency range from a fraction of a hertz to several hertz. At about 3 hertz there is a resonant beam response to the ground motion. However, by using a feedback system, ground motion of the order of 0.01 mil (rms averaged over the site) amplitude in this frequency range can be controlled. A larger ground motion may require a feedback system stronger than envisaged, and therefore would be undesirable.

G. CLIMATE

Climate will have a direct influence on SSC operational cost and efficiency. Average temperature and humidity levels will affect heating and cooling system capacities and operating costs. Adverse weather will also affect operational productivity. Summers with low humidity and few severe storms and winters with low accumulations of snow would be most advantageous. A seasonal average mean temperature of 35°F or greater in winter and an average mean temperature of 80°F or less in summer would represent a desirable climate range. Similarly, a relative humidity range of 25 to 70 percent, coincident with the summer average mean temperature stated above, would be desirable. The economic effect of local climate on operation and construction must be taken into account.

H. COST AND SCHEDULE

Economies in construction cost and schedule are important factors to consider and plan for at the SSC. The cost and time to construct the SSC will be strongly dependent upon site geological, geohydrological, and climatic conditions. The tunnels and accesses are major cost elements in the project, and existing experience with underground construction in the region of the site should be noted.

Annual operating costs, including those based on local wage scales, utility rates, transportation charges, etc., must be considered. Operating and construction costs must be evaluated over the long term to achieve an optimum balance. Substantial savings can be achieved through preferential utility rates and road maintenance concessions.

Donation of land for the site and availability of existing buildings and facilities in the vicinity would affect favorably both cost and schedules.

PART IV. INFORMATION NEEDED ABOUT PROPOSED SITES

This part of the document addresses the kinds of information needed about a proposed site in order to assess its suitability. The information needed is organized into eight sections corresponding to the criteria sections used in Part III.

The sections have a consistent format. The opening paragraphs of each section describe and explain some of the important aspects of the information that would be needed about proposed sites. Following these paragraphs are itemized statements that define the needed information. This format has been chosen in order to clarify as much as possible the particular aspects of each issue that are judged most important.

Selected information topics have been identified as necessary for a first overall assessment of the strengths and weaknesses of any site. It is envisioned that DOE might ask that these be addressed in a preliminary response from the proponents of a site. The items that have been recommended for preliminary attention are enumerated below and marked with asterisks (*) in the text.

A. Setting
    1.(ii)., 1.(iii)., 2.(ii)., 2.(iii)., 4.(i).

B. Environment
    1.(i)., 2.a.(i)., 3.a.(ii)., 3.b.(ii)., 7.(ii).

C. Geology and Tunneling
    1.(i)., 2.(i)., 3.(i)., 4.(i)., 5.(iii).

D. Community Resources
    1.(i)., 2.a.(i)., 3.a.(i)., 3.b.(i)., 5.(i).,
    6.(i)., 6.(iii)., 7.(i).

E. Utilities
    1.(i)., 2.(i)., 3.a.(i)., 3.b.(i).

F. Man-made Disturbances
    1.(i)., 2.(i).

G. Climate
    1.(i)., 2.(i).

H. Cost and Schedule
    1.(ii).

A. SETTING

1. General

Because the SSC will be such a large facility, it is likely to be located near a number of communities. For each proposed site, an evaluation of possible interferences with existing man-made facilities should be addressed, (e.g., residential, commercial, agricultural, industrial or other developed areas that could be affected by the construction or the operation of the SSC).

SSC construction could affect features such as surface-water courses, prominent geologic features, vegetation of some unique or special character, ground water used for shallow-well supplies, etc. Possible effects upon natural features by the SSC construction or operation should be assessed.

Information Needed

(i). An overall assessment of the suitability of the proposed region(s) for siting the SSC based on the general siting needs described earlier,

* (ii). An indication of how the SSC facilities could best be placed within the area(s) proposed, using a current edition of the USGS 7-1/2 minute or similar quadrangle map sheets as a base.

* (iii). A narrative describing the proximity and extent of relevant man-made and natural features of the region that have a bearing on the siting.

(iv). A description of the measures that might be taken to deal with interferences with existing man-made or natural features.

2. Land Commitment

The lands required to be committed for the SSC by acquisition or easements were defined in Part III. Various options might be used singly or in combination to achieve the objective of Federal jurisdiction over the lands. At minimum, however, the United States must obtain fee simple title to those areas where surface facilities are to be located. For the land commitment option or options proposed, constraints, pending actions, issues of possession and use, concerns for existing uses and improvements, and related cost, if any, or time impacts would have to be identified.

Information Needed

(i). A site land area commitment proposal, taking into account the objectives, issues, and concerns set forth in Part III.

* (ii). The cost, if any, to the Federal Government of obtaining the required possession and use of lands required for the construction and operation of the SSC.

* (iii). A description of the issues, actions, or proceedings that must be brought to a conclusion in order to be in a position to commit the property or property-use rights as indicated, including an estimate of the time required to complete the project.

(iv). Discussion of the schedule and interface required between project, state, and Federal Government.

(v). Discussion of the degree of local awareness of the proposed land area commitment, and the degree of support or opposition likely to be encountered.

3. Institutional Setting

a. Regulations

The SSC will be a Federal facility, and the U.S. Government is not subject to many state and local requirements. Nevertheless, matters of land-use policy, zoning and the objectives of a General Plan would be affected, as would requirements and procedures for issuance of permits and licenses. Local matters such as water-rights ownership, adjudication and availability, and air-rights policies would also be affected. Issues would arise related to local administration of subsurface easements, mineral rights, and oil and gas rights.

Information Needed

(i). Specific information regarding the existing laws, regulations, policies, codes, plans, ordinances, rights, or other local statutes and jurisdictions that would be affected by the SSC or that could affect the SSC at the site proposed.

(ii). A discussion of the measures required to satisfy, mitigate or otherwise deal with the matters identified, and the time required and proposed schedule for such proceedings.

b. Taxation

Each political jurisdiction requires sources of revenue to carry out its role as set by the public. The introduction of the SSC and the commitment of substantial land areas to the Federal Government for the laboratory would have an effect on local tax revenue sources. Any local special assessment district such as irrigation, power, fire protection and public safety, schools, roads, etc., that is currently relying upon property tax revenues to meet debt obligations of the district that would be affected by the proposed Federal facilities, would need to be identified.

Information Needed

(i). An analysis of the current tax revenues, by jurisdiction, that are derived from the lands, improvements, business conducted or other taxable sources in the area or on the lands proposed for use by the national laboratory.

(ii). An indication of the position of the host state and other local bodies with regard to tax policies if considered applicable to transactions and properties involved with the construction and operation of this national laboratory.

(iii). Costs, if any, that might be borne by SSC that are related to taxation, tax policy, tax revenue, impact payments or related matters.

c. Employment Practices

Employment practices and active Affirmative Action in implementing fair employment practices within the state and the region proposed for siting the SSC are of critical concern to this project. The SSC National Laboratory will be an Equal Opportunity employer. All qualified people will be eligible for employment and there will be no discrimination because of race, color, religion, sex, national origin, age, or handicap. Affirmative action will be taken to achieve the full realization of equal opportunity.

Information Needed

(i). Evidence with regard to the current policies and history of compliance with Federal fair employment practices, with Equal Employment Opportunity statutes, and with open housing practices.

4. State and Local Government Support

As described in Parts II and III, there are a variety of services, facilities, support needs, and areas of institutional assistance where the support of state and local government will be essential to the creation of the SSC. Beyond the previously discussed concerns about setting, assistance by state and local government in securing the necessary utility services will be essential to the successful construction of the SSC.

Transportation facilities, including highways, roads, railroads, and airports, will play a key role in mobilizing for SSC construction and later operation. As discussed in Part III, a timely commitment and initiative on the part of state and local government (or other competent authority) to provide these facilities would be desirable.

There will be ample opportunities for strong and effective cooperation between local, state, and Federal agencies in bringing about the economic and scientific success of the SSC National Laboratory.

Information Needed

(i). An overall description of the nature and extent of proposed state and local government support in facilitating the siting, construction, and operation of the SSC.

(ii). A description of the state and local support that is offered in the areas of permitting and procedural assistance; securing of utility accesses and connections; and providing and/or maintaining access roads, highways or other site facilities.

(iii). Services and support that local and state government may be able to provide in assisting in the construction and operation of the SSC.

B. ENVIRONMENT

The SSC will be constructed and operated with minimal and acceptable environmental impact. The Department of Energy will comply with the requirements of the National Environmental Policy Act (NEPA) and will prepare an Environmental Impact Statement (EIS) that presents an analysis of the impacts of construction and operation of the SSC.

The siting of the proposed SSC is significantly dependent upon identification of the environmental characteristics of the immediate area and its surrounding environs. It is also very important to be able to identify the significant effects of the SSC on the environment. Evaluations need to be made by considering environmental characteristics such as land use, surface water, ecology, air quality, and historic and archaeological resources.

1. Land Use

An environmental concern with respect to land use is the identification of wetlands, prime or unique farmland as designated by the Soil Conservation Service of the U.S. Department of Agriculture, the Special Area Management Plan of the Office of Coastal Zone Management of the National Oceanic and Atmospheric Administration (if applicable), National and State parks, forests, etc., and any local jurisdiction zoned land uses that may be impacted by the SSC.

Information Needed

* (i). A discussion of existing and proposed uses of the lands within and adjacent to the SSC project.

(ii). Aerial photographs, maps, drawings, or other graphics sufficient to show the location, extent, and nature of the land uses referred to under (i) above.

(iii). Identification of lands that could be used for disposal of excavated spoils.

2. Surface Water

The construction and operation of the SSC will impact the surface-water hydrology of the proposed site, including water quantity, water quality, flooding and drainage, and low flow/drought.

a. Quantity

It is important to identify any drainage basins and major surface-water features such as streams, lakes, reservoirs and other water courses that may be in the region of a proposed SSC site. Water flow and volume information will be required in sufficient detail to determine normal and seasonal variability making use of historical records of flow and volume.

Information Needed

* (i). A map delineating major drainage basins and identifying major surface-water features.

(ii). The baseline and seasonal variations in quantity for the surface waters.

b. Quality

The surface waters identified above will have seasonal variations of quality. Water quality may be temporarily affected by the construction and operation of SSC. Water quality information should include: nutrients, pH, total residue, nonfiltrable residues, dissolved oxygen, total alkalinity, significant heavy metals, temperature, and turbidity.

Information Needed

(i). The baseline and seasonal variations in quality for the surface waters identified.

(ii). An estimate of the effect on surface-water quality of the construction and operation of the SSC.

c. Flooding/Drainage

The proposed construction or operation of the SSC may be affected by extreme flows in the surface waters, as well as other drainage difficulties such as poorly draining soils. Useful information would contain available flood mapping (i.e., HUD or COE Flood Plain maps), historical flooding information (profiles or spot elevations), and would identify special drainage difficulties due to surface or subsurface conditions.

Information Needed

(i). Identification on maps of the extent of flood areas and corresponding flood frequency.

(ii). The pattern of historical and anticipated flooding and drainage conditions for the surface waters within the SSC project area.

(iii). Special drainage difficulties that might be anticipated in the proposed project area.

d. Low Flow/Drought

A drought over a sustained period of time could be a serious problem for the SSC. Since water will be needed for a variety of uses, it is not practicable to define a drought specific limitation for the project at this time.

Information Needed

(i). Recorded drought or low-stream histories for surface waters in the region of the proposed SSC site, including the most severe dry period and low stream flows on record.

3. Ecology

The construction and operation of the proposed SSC project may impact the fish, wildlife, and botanical resources in the project area. The ecological resources in the area must be evaluated under each of these categories.

a. Fish and Wildlife

Fish and wildlife may be impacted by the proposed SSC project. Some species may be considered important because of their commercial or recreational value. Other fish or wildlife in the area may be proposed for listing or are listed as threatened or endangered by the U.S. Department of the Interior or Department of Commerce.

Information Needed

(i). Description of the significant fish and wildlife resources in the vicinity of the proposed SSC project area and their locations.

* (ii). The habitats of threatened or endangered species and any species in the project area that receive any other type of special protection.

(iii). A map showing the distribution of the fish and wildlife discussed under items (i) and (ii) above.

b. Vegetation

SSC construction and operation might impact the botanical resources of a proposed site by permanently altering the terrain, or by excavation and heavy traffic during construction. Of particular concern are vegetation types and plant species proposed or listed as threatened or endangered by the U.S. Department of Interior and Department of Commerce.

Information Needed

(i). Description of the significant botanical resources in the proposed SSC project area.

* (ii). The habitats of threatened or endangered species.

(iii). A map showing the distribution of vegetation types discussed under items (i) and (ii) above.

4. Air Quality

The air quality at the proposed SSC site will not be affected by the project during operation; however some dust and noise problems will be encountered during construction. To evaluate these, a summary will be needed of meteorological conditions affecting the dispersion of air pollutants and current and historical data on ambient air quality. The attainment status of the air-quality control regions containing the site is relevant to any evaluation.

Information Needed

(i). Data on the existing air quality, and the air-quality limitations for the proposed SSC site.

(ii). Anticipated cost of mitigation required in non-attainment areas.

(iii). Factors affecting dust generation including soil types and local conditions.

5. Background Radiation

The issues of radiation and radioactivation will be addressed by the SSC staff. Therefore, baseline information on the existing background radioactivity of the soil and water in the area of the proposed site is necessary.

Information Needed

(i). Available background data pertaining to soil and ground-water radioactivity levels in the region of the proposed site.

(ii). Information about local dose rates due to natural background radiation.

6. Historical and Archaeological Resources

Historical and archaeological resources are a national trust. Information should be provided to identify historic or archaeological resources within or near any proposed project area; the results of any surveys, inventories, and subsurface testing that may have been performed by local state and Federal agencies; places that are on the National Register of Historic Places; and other such information that is available from the state historic preservation officer or similar state official.

Information Needed

(i). Description of the historical and archaeological resources in the proposed SSC project area.

(ii). Discussion of any potential effects on historical and archaeological resources that might result from siting, constructing, or operating the SSC in this area.

7. Preliminary Environmental Evaluation

A preliminary evaluation should be made of the possible environmental impacts associated with the proposed construction and operation of the SSC project in the proposed area. The evaluation should specifically address the environmental characteristics covered above.

Information Needed

(i). A preliminary environmental evaluation of each site including a discussion of mitigation or protection measures.

This environmental evaluation will be used to help fulfill the requirements for NEPA compliance.

* (ii). Identification of major impacts that would require special attention or that could limit the use of the proposed site.

(iii). The possible impacts of the proposed SSC project on other environmental characteristics such as socio-economic resources, recreational resources, and aesthetic or visual resources.

C. GEOLOGY AND TUNNELING

Surface and subsurface conditions will directly affect the design and construction of nearly all structures of the facility. The largest single structural component, the collider ring, will be constructed underground. Ground conditions can materially affect the cost and schedule of its construction, and, possibly, the feasibility of construction.

1. Topography

Topography is significant because it is the primary determinant of the variation in depth of cover above the collider tunnel. Since depth has an impact on the probable types of tunneling, access shafts, and the design of experimental areas, topographic conditions must be carefully considered.

Information Needed

* (i). An illustration of the proposed location and profile of the SSC showing the maximum and minimum depths of cover for the collider, injector, and experimental areas based on topographic maps (either the same USGS maps furnished under Section A or other more detailed mapping).

2. Geology

The geologic setting defines, to a large measure, the principal geotechnical characteristics of a site. For construction purposes, relatively uniform geologic characteristics are preferred. Structural features, such as faults or shear zones, or buried valleys in the bedrock, may pose local construction difficulties, especially if associated with large quantities of ground water. Soft soil conditions such as certain clay deposits will require special, and often costly, tunneling or deep excavation methods and may pose foundation problems for surface facilities.

Information Needed

* (i). Geologic maps of the site area that define major geologic units to the depth of interest, together with an engineering description of these units.

(ii). Identification of significant structural geological features that may pose construction problems.

(iii). Locations and extent of soft clay, unconsolidated sand, or other soil conditions that may pose tunneling, excavation, or foundation problems.

3. Geohydrology

Ground water may pose significant underground construction problems in pervious soils or when rock tunnels traverse pervious geologic structures and shear zones. As a practical matter, tunnel construction at depths greater than about 100 feet in unconsolidated granular soils containing ground water becomes very difficult. Pervious structural features in rock can usually be consolidated, but tunneling through a number of such features would be time consuming and costly. Excavation for cut-and-fill tunnels and shafts in water-bearing ground is also difficult and may require costly and time-consuming construction methods.

The chemical content of the ground water may have an effect on the choice of construction methods. Certain types of ground water could pose problems of dewatering and water disposal during construction. The corrosivity of the water and the geologic material may require special provisions in the selection of construction materials and corrosion protection.

Information Needed

* (i). Detailed characteristics of the overall geohydrological regime including ground water, and the interaction with surface streams and precipitation.

(ii). The depth to ground water and annual variations in ground water levels around the site.

(iii). Current and proposed ground-water use.

(iv). Identification of locations where underground construction may be impacted as a result of ground-water pressure or inflows, or by chemical constituents of the ground water, including alkalinity and salinity.

4. Seismicity

In a seismically active area special design provisions may be required.

Information Needed

* (i). A characterization of site seismicity, in terms of zone designation according to the Uniform Building Code. If in Zone 3 or 4, additional site-specific seismic data should be obtained.

(ii). An estimate of the site-specific maximum credible event.

(iii). Identification on the map of any faults in the site area that are known or suspected to have been active in the last 10,000 years.

5. Tunneling and Underground Construction

Reference has been made in previous sections to the topography, the geologic setting, and the geohydrology. The impact of these features on the feasibility, cost, and schedule of construction cannot be assessed without information about the soil and rock along the proposed alignment of the underground structure.

Information Needed

(i). Geologic information indicative of that along possible SSC alignments, showing relevant geologic units, structural features and topography, aquifers, and ground-water table.

(ii). An engineering description of relevant soil and rock units, including a description of potential local construction difficulties associated with geologic structures and anomalies based upon existing data.

* (iii). A recommended construction approach for the conditions present on each proposed site. Any features that require novel or unusual methods should be indicated.

D. COMMUNITY RESOURCES

Beyond the technical necessities, such as land availability and suitable geological conditions, are a number of other desirable regional characteristics, including the availability of skilled labor, housing and other community services, industrial resources, educational and research facilities, recreation, and cultural resources in the vicinity of the proposed site.

1. Human Resources

In addition to scientists, the accelerator laboratory will require mechanical, electrical, and civil engineers, architects, programmers, machinists, technicians for accelerator operation and experimental setup, computer operators, designers, and other similarly skilled and semi-skilled personnel. A region should have available a labor pool that permits recruitment and retention of qualified personnel for construction and operation of the SSC.

Information Needed

* (i). A description of the geographic distribution of population in relation to the proposed site.

(ii). A description of the labor pool and prevailing wage rates in the region.

(iii). Regional employment trends by industry and occupation, e.g., growth in high-technology employment in the state.

(iv). A demographic profile of the existing and projected population in the region.

2. Housing and Community Services

The SSC is a complicated device that will operate 24 hours a day, so personnel must live relatively close to the site. It should be located near a community or communities that can provide and/or develop housing and other necessary services for the 3000 full-time and visiting scientists and staff. The laboratory will be an Equal Opportunity employer, and this practice must be reflected in housing availability.

a. Housing

Housing needs typically include:

Single-family homes for sale or rent in nearby communities (single-family detached units, townhouses and condominiums).

Single-family homes or apartments available for rent for visitors and staff.

Motels and hotels for short-term visitors.

Information Needed

* (i). Characterization of housing available or planned in the region.

(ii). Description of housing distribution, typical purchase prices and rents for the housing types mentioned above.

(iii). Description of the potential for future housing supply.

b. Community Services

Community facilities and services including recreational, medical, and public services facilities are needed in the region of the SSC.

Information Needed

(i). Identification of medical centers, hospitals, and emergency services including the number of beds, size of staff, and other relevant information.

(ii). Information on the availability and responsive capability of police and fire and rescue services in the nearby communities.

(iii). A description of community recreational and open-space facilities including parks, centers for spectator and participatory sports, and other areas for recreation.

3. Accessibility

Adequate transportation facilities should be available to the proposed site to permit convenient and efficient access for the traffic of personnel, materials, and equipment required in the construction and operation of the SSC. The site should be served by a system of Interstate and state highways, and local roads of sufficient capacity to accommodate the additional traffic expected to be generated by SSC. Regional public transportation should be available to serve the SSC main campus. Highway travel between SSC and a major urban center should be convenient.

a. Airports

There should be a major airport convenient to the SSC because the research to be conducted there will attract a steady flow of scientists and other visitors from around the nation and the world.

Information Needed

*

(i). Information on size, location, and service characteristics of local, regional and/or international airport(s) in the vicinity of SSC.

(ii). The number and size of air carriers, number of scheduled daily arrivals and departures, and the destinations directly served.

(iii). Operational limitations, such as the average number of days per year the airport is closed because of bad weather.

b. Highways, Streets, and Roads

Highways, streets, and the road network in the vicinity of the proposed site are important to the configuration of the SSC. Access roads and highways must be able to accommodate long-bed (HS-20-44 design) vehicles as specified by the American Association of State Highway and Transportation Officials (AASHTO).

Information Needed

*

(i). The present characteristics of the major routes serving the site, including vehicle restrictions (length, weight, height), route capacity (vehicles per hour), and peak traffic rates.

(ii). Identification of any improvements to the existing road and highway network needed to support the construction and operation of the SSC at the proposed site.

(iii). Statements on maintenance responsibility for access roads and highways serving the site.

c. Public Transportation

Once in operation, the SSC will attract a regular flow of visiting scientists and other visitors who because of their non-resident status will depend on public transportation to and from the site. Availability of various types of transport, such as intercity rail and/or bus, regional bus, vanpool, limousine, taxi, and rental cars, would be desirable.

Information Needed

(i). A description of available public transportation systems and services in the vicinity of the proposed site including airport access.

(ii). Discussion of the improvements to the public transportation systems and services required to adequately serve the SSC.

d. Railroads and Waterborne Transportation

Availability of rail transportation in the vicinity of the site is desirable. If the proposed site is near a navigable waterway, it might be advantageous alternatively to transport certain bulky equipment and/or materials to the site by water.

Information Needed

(i). The type and extent of rail service available in the vicinity of the SSC site.

(ii). Service characteristics, available connections to Class 1 railroad mainlines, and existing load limitations where known.

(iii). Assessment of the capability of the available rail system to handle special equipment and supplies needed for the construction and operation of the SSC.

(iv). Description of any waterborne transportation facilities and services available to the proposed site.

4. Construction Resources

The SSC will require large amounts of conventional construction materials and equipment. Sources of supply will be required for these critically needed items:

Cement and aggregate material
Steel fabrication services
Electrical power equipment
Mechanical systems equipment
Construction equipment maintenance and repair

Information Needed

(i). Description of sources of construction materials and equipment with indication of their adequacy.

5. Industrial Resources

A large accelerator such as SSC will require many specialized and conventional industrial services. It would be desirable for as many of these as possible to be available in the immediate area. Some of the most important of these services are:

Sources of compressed and liquefied gasses (He, N_2, O_2)

Sources of industrial solvents

Electrical and electronic fabricators

Heavy-equipment maintenance facilities (for rewinding generators, turning shafts, etc.)

Specialized heavy-equipment rental

Maintenance services— vehicles, computers, office machines

Vendors' regional warehouses with fast service on parts

Information Needed

* (i). Discussion of the accessibility of the proposed site to an industrial base to support the construction and operation of the proposed SSC.

(ii). Characterization (capacity, distance) of the nearest source capable of supplying liquid nitrogen (LN), and purified helium.

6. Educational and Cultural Resources

Proximity of the site to universities, research centers, and other educational institutions is desirable. Nearby campuses could be valuable sources of professional personnel for the SSC as well as offering continuing education and library access opportunities to the staff.

Community colleges and technical schools are other valuable resources that would offer continuing education opportunities for the SSC staff and could attract and develop technically skilled labor for the SSC operation.

The quality of elementary and secondary education is often a decisive factor for families considering relocation. Quality education could help attract professional personnel needed for the SSC.

A consideration in determining the attractiveness of a site and its potential for retaining SSC staff is the proximity and extent of cultural resources.

Information Needed

* (i). Identification of all higher educational and research institutions in the vicinity of the proposed SSC site.

(ii). Brief descriptions of the enrollment, curricula emphases, faculty size, and other relevant information for the institutions identified above.

* (iii). Description of elementary and secondary educational facilities for children of permanent staff members and long-term visitors.

(iv). The numbers and capacities of public and private schools, current enrollment levels, student/teacher ratios, SAT or ACT score averages for the last 5 years, evidence of community attitude about education, expenditures per pupil for the last 5 years, fiscal health, and other indications of educational quality are some of the needed information.

(v). Description of libraries, museums, performing arts centers, places of worship, and cultural resources in the vicinity of the proposed SSC site.

7. Community Support and Assessment

Community support will play an important role in the ultimate success of the SSC. It will actively seek the support of the surrounding communities by establishing a good-neighbor policy. It is important to determine at an early stage what community support exists and how strong any opposition might be to siting the SSC in a region.

Information Needed

* (i). Discussion of the community support for the proposed SSC that exists and its likelihood of growth.

(ii). A characterization of any opposition known to exist, or anticipated, in siting the SSC as proposed.

E. UTILITIES

As discussed in Part III, utility supply availability, capacities, and costs are important considerations for the SSC. Sufficient supplies of water and electric power are particularly crucial. Electrical power requirements will depend significantly on the cooling systems designs finally selected. Design of the industrial cooling system, will be largely influenced by climatic conditions, particularly wet and dry bulb temperatures, wind, and the availability and quality of cooling water sources.

Availability of industrial cooling water is a major requirement for the proposed SSC. Most of the cooling water will be used in the collider ring, and to a lesser extent in the injector and central laboratory. As described in Part III, limited availability of cooling water would increase the power demand significantly, as much as 25%. Accurate information relative to the availability of industrial cooling water is needed both for summer and winter months. Available sources, water quantity and distribution, quality and utilization of return flows are the main issues to be considered.

If improvements to the utility systems are required to meet the SSC's requirements, a timely commitment on the part of the proposer to make these improvements would be essential.

A complete system of telecommunications will be required to support the operation of the SSC. An adequately sized regional communications network will be required. Local and intra-facility communications links will also be required.

1. Power

Primary power could typically be supplied to the SSC site at transmission voltage in the range of 230 kV to 500 kV. Separate feeds, connected to different points on the grid, will be required to provide adequate reliability. Generating capacity and power grid stiffness are of concern. For purposes of estimating power requirements and rates, one can assume the following operating cycle for the major machine components, including particularly the refrigerator/compressor equipment:

Time	Mode of Operation	Ave. Power Requirement
2/3 year	Full	100%
1/3 year	Stand-by	40%

Information Needed

* (i). A description of the electric power generating and transmission grid system, including location of generating stations, type of primary energy sources, and generating capacities.

(ii). A map of the transmission network showing lines, voltages, and capacities, including the location of switching stations and substations.

(iii). An analysis of the power system stability at the proposed SSC site, including both steady-state and transient stability evaluations.

(iv). Experience with the reliability of electrical power service.

(v). Utility rate schedules that include energy and demand charges for an industrial load represented by the SSC. Indicate any preferential rate concessions for the SSC and their duration.

(vi). Projection of future power demand growth and future costs in the region including an evaluation of how the SSC would impact this projection.

2. Fuel

Heating required for SSC is expected to vary from 55,000 MBtu/hr for a desirable climate representing 900 degree-days (base 65°F) for a winter month, to 73,000 MBtu/hr for a colder climate with a 1200 degree-day winter month. Information on fuel availability, reliability of supply, and cost for all fuel types available to the site, including as applicable natural gas, coal, oil, solar, and geothermal is desirable.

Information Needed

* (i). Description of how the fuel heating/cooling requirements for the SSC could be met.

(ii). The cost factors in dollars per million Btu per hour ($/MBtu/hr).

3. Water

Information on sources of usable water, means of conveyance, treatment requirements and cost is relevant to utility considerations. Other aspects, such as availability of water rights or environmental impacts are dealt with in other sections.

a. Industrial Cooling

To meet the needs of the SSC systems it will be necessary to consider the available sources of water, water quantity and quality, seasonal variations, and flow rates. Sources may include surface water, ground water, spring water or any other locally available suitable source. For underground water sources, location of wells, nature of aquifers and the ground-water potential of the underground basin will be relevant. Cooling water should comply with applicable standards.

Information Needed

* (i). Itemization of the available sources of water proposed for use as industrial cooling water in the format shown in Table A.

(ii). The estimated cost of industrial cooling water delivered to the site ($ per million gallons) based on the resources listed in Table A.

(iii). Description of the physical and chemical properties of the water available for use as industrial cooling water and any treatment that may be required.

TABLE A

SOURCES OF WATER AND FLOW RATES
(MILLION OF GALLONS PER DAY)

Name of Source	Distance from Site (Miles)	Surface Water Flow Rate		Spring Water Flow Rate		Other Sources Flow Rate	
		S	W	S	W	S	W
1.							
2.							
etc.							

S - Summer; W - Winter

b. Potable

The quality of water available at the site will play an important role in determining its suitability as potable water. The quality of potable water must comply with the National Interim Primary Drinking Water Regulations and the state's drinking water quality standards.

Information Needed

* (i). Itemization of the sources of water available for use as potable water. (Refer to Table A.)

(ii). Estimates of the present and projected cost of potable water delivered to the site ($ per million gallons).

(iii). Discussion of whether the quantity of water available, particularly during periods of low flow, will be sufficient to support the SSC population.

(iv). The expected physical, organic, and biological properties and chemical composition of the water after treatment.

4. Waste Disposal

SSC facilities will generate both liquid and solid wastes; both must be disposed of properly. Information on the availability, capacity, and proximity of environmentally acceptable disposal sites or other means of solid waste disposal should be obtained.

a. Sewage Disposal

It is anticipated that the sanitary network for the campus, including the industrial and injector areas will be served by a pipe collection system discharging to a centralized sewage treatment plant or to an existing sewage treatment plant, if such a facility is available in the vicinity.

Information Needed

(i). A description of the available treatment facilities that might be used to serve SSC, including proximity to the site and cost of connection.

b. Solid Waste Disposal

The quantity of solid waste to be generated at the SSC facility is expected to be about 30,000 cubic yards per year. The SSC may elect to dispose of this solid waste in an on-site landfill or choose other options such as incineration or off-site disposal, including recycling.

Information Needed

(i). Identification and description of what type of solid waste disposal resources are available for SSC's use.

(ii). Identification of any existing or proposed landfill, incineration or recycling plant near the proposed site.

5. Telecommunications

A high-speed digital telecommunications system will be required to support the operation of the SSC. It is anticipated that the SSC facility will include a Private Automatic Branch Exchange (PABX) with an estimated capacity of 4000 lines and 200 trunks.

Information Needed

(i). A description of the extent and proximity of existing switching stations, including the number of trunks available.

(ii). An estimate of the anticipated costs, including connection and usage fees, for the required external communications system.

(iii). A forecast of anticipated growth of the regional system demand, the impact of the SSC facility on the forecast, and the planned activity to meet the forecasted demand.

F. MAN-MADE DISTURBANCES

1. Vibration

As noted in Part III, the particle beams in the SSC have cross-sections of less than one thousandths of an inch, but must be held in collision for many hours. For this reason, the SSC is very sensitive to vibrations that would displace the beams from one another. These vibrations could be occasional, as from blasting operations, or continual, as from heavy trucks, rail traffic, or operation of heavy machinery.

Information Needed

* (i). An identification of sources of vibration such as major highways, railroads, quarries, or heavy machinery operations present in the area, and an estimate of their intensity.

2. Noise

It will be necessary to evaluate the effect of noise in and adjacent to a proposed site. Information on principal sources and levels of noise in a proposed project area will be needed.

Information Needed

* (i). Identification of the principal sources and levels of background noise in and around the proposed SSC project area.

(ii). Noise contours of areas in and adjacent to the proposed site, if available.

(iii). Identification of noise-sensitive land uses located in any project area.

G. CLIMATE

The schedule and cost of construction, as well as the long-term operational cost of the laboratory, will be significantly influenced by local climatic conditions. Extreme conditions of temperature, humidity, wind, rain and related flooding, snow and ice, fog, and the duration of such extremes are of practical concern. Adverse conditions would directly affect design and construction activities and also influence the long-term operating efficiency and costs of the SSC.

The kinds of information needed on climatic conditions (averages, extremes, durations, and frequencies) are delineated below.

1. Temperature and Humidity

Table B lists recommended categories of information on temperature and humidity. Sources of information should be identified with respect to the location of weather reporting stations and periods of record along with other qualifying information.

Information Needed

* (i). Temperature and humidity data. (Refer to Table B.)

(ii). The average winter frost penetration. (Refer to Table B.)

TABLE B
AVERAGE CLIMATIC CONDITIONS BY MONTHS

Month	Average Low Temp. (F°)	Average High Temp. (F°)	Average Relative Humidity (%)	Average deg-days (base 65°F)	Average Frost Penetration (in.)	Precip--itation (in.)
Jan. through Dec.						

2. Precipitation

The amount of precipitation in solid form (snow, ice, hail, sleet) or liquid (rain) that falls on a proposed SSC project area will be important during both construction and operating phases.

Information Needed

* (i). The average monthly precipitation. (Refer to Table B.)

(ii). The frequency and duration of precipitation extremes and depths of snowfall.

3. Wind

Wind transports dust, silt, and sand and is also a structural concern because of possible extreme wind forces.

Information Needed

(i). The prevailing wind direction and speed. (A wind rose, if available, should be obtained.)

(ii). Information on extreme wind conditions (magnitude, frequency and duration).

4. Regional Storms

Severe weather conditions will affect the time schedule and cost of construction as well as the operation of the SSC project. The types of storms that need to be considered include large air-mass movements, fronts, squall lines, hurricanes, tornados and convective weather such as thunderstorms.

Information Needed

(i). Description of the regional storm characteristics including types, frequency of occurrence, and severity.

5. Insolation

The amount of sunshine, i.e., the intensity of solar radiation and the number of clear days per month, that is available for heating and cooling of the SSC facilities is of interest.

Information Needed

(i). The daily average solar irradiation in Btu/sq ft for summer and winter months.

(ii). The average number of clear days per month.

H. COST AND SCHEDULE

The foregoing sections have itemized specific information bearing on various cost and schedule factors for the SSC.

1. Cost Factor

In the construction area the information would yield desirable data on costs for land, water supply, electric power connections, roads, and other facilities. For operation the cost of electrical power, fuel, transportation, maintenance, etc., must be considered both year by year and over the lifetime of the facility.

Information Needed

(i). Summary of cost information relevant to the siting, construction, and operation of the SSC.

* (ii). Assistance and concessions that might be offered with respect to locating the SSC in the proposed region.

DOE/ER-0216

NUCLEAR PHYSICS ACCELERATOR FACILITIES

JANUARY 1985

U.S. DEPARTMENT OF ENERGY
OFFICE OF ENERGY RESEARCH
DIVISION OF NUCLEAR PHYSICS
WASHINGTON, D.C. 20545

TABLE OF CONTENTS

Page

Overview.. 1

Argonne National Laboratory - ATLAS.............................. 5

Brookhaven National Laboratory - Tandem/AGS Heavy Ion Facility.. 7

Duke University - Cyclograaff..................................... 9

Lawrence Berkeley Laboratory - SuperHILAC/Bevalac................. 11

Lawrence Berkeley Laboratory - 88-Inch Cyclotron.................. 13

Los Alamos National Laboratory - Clinton P. Anderson Meson Physics Facility... 15

Massachusetts Institute of Technology - Bates Linear Accelerator Center.. 17

Oak Ridge National Laboratory - Holifield Heavy Ion Research Facility.. 19

Texas A&M University - Texas A&M Cyclotron........................ 21

University of Washington - Tandem/Superconducting Booster Accelerator... 23

Yale University - Tandem Van de Graaff............................ 25

Statistical Information

Beam Hours for Research.. 27

Nuclear Physics Funding.. 28

Accelerator Facility Starting Dates............................ 31

Nuclear Physics
Accelerator Facilities

OVERVIEW

Introduction

Nuclear knowledge, techniques, instruments, and applications pervade American society. These serve as the basis for our national defense strategy, for therapeutic and diagnostic medical applications, for generation of electricity with nuclear reactors (fission now and fusion in the future), and for a large and diverse array of applications in industry. The behavior of nuclei and nuclear matter determines the physical properties of our universe--from its creation from a primordial mix of energy and elementary particles to the reactions which power our sun to the makeup of our planet. Thus, basic nuclear research is both a central component in America's long term investment in its technological future with nuclear processes and it is also essential to any basic understanding of the world about us.

The Department of Energy's Nuclear Physics program is a comprehensive program of interdependent experimental and theoretical investigations of atomic nuclei. Long range goals are an understanding of the interactions, properties, and structures of atomic nuclei and nuclear matter at the most elementary level possible and an understanding of the fundamental forces of nature by using nuclei as a proving ground. Basic ingredients of the program are talented and imaginative scientists and a diversity of facilities to provide the variety of probes, instruments, and computational equipment needed for modern nuclear research. Approximately 80% of the total Federal support of basic nuclear research is provided through the Nuclear Physics program; almost all of the remaining 20% is provided by the National Science Foundation. Thus, the Department of Energy (DOE) has a unique responsibility for this important area of basic science and its role in high technology.

Experimental and theoretical investigations are leading us to conclude that a new level of understanding of atomic nuclei is achievable. This optimism arises from evidence that: (1) the mesons, protons, and neutrons which are inside nuclei are themselves composed of quarks and gluons and (2) quantum chromodynamics can be developed into a theory which both describes correctly the interaction among quarks and gluons and is also an exact theory of the strong nuclear force. These concepts are important drivers of the Nuclear Physics program.

Long Range Planning

Long range planning, scientific community input, and coordination of Department of Energy work with National Science Foundation (NSF) activities take place through a variety of channels. The most important of these channels are external and internal review of specific research areas, frequent staff contact with counterparts at the National Science Foundation, and the work of the DOE/NSF Nuclear Science Advisory Committee (NSAC). In cooperation with the DOE and NSF, NSAC has developed a long range plan for basic nuclear research in the United States--"A Long Range Plan for Nuclear Science" (December 1983). This plan is based upon a comprehensive review of scientific advances and opportunities which have emerged since the development of the previous long range plan--"A Long Range Plan for Nuclear Science" (December 1979).

The 1983 Long Range Plan strongly reaffirms NSAC's April 1983 recommendation that construction of a 4 GeV, continuous electron beam facility be initiated as soon as possible, and it identifies a longer term, high priority need for a relativistic heavy ion collider facility. In the fall of 1984, NSAC reviewed the 1983 Long Range Plan from the perspective of scientific developments which had occurred over the previous year. NSAC found that the scientific priorities and recommendations of the 1983 Long Range Plan remained valid--"Review of the 1983 Long Range Plan for Nuclear Science" (November 1984).

From very different aspects, both the electron facility and the heavy ion collider share the common scientific goals of understanding quantum chromodynamics as an exact theory of the strong nuclear force and understanding the ways in which the quarks and gluons inside mesons, protons, and neutrons determine the behavior and makeup of nuclei. Also, in the interaction of very energetic colliding beams of heavy ions, extreme conditions of mass and energy density will occur, conditions which hitherto have prevailed only in the early instants of creation of the universe. The mass and energy densities will be so great that transitions to new phases of nuclear matter seem likely. If these bright prospects can be realized, a new level of knowledge of atomic nuclei will be achieved.

Accelerator Facilities

Success of the Nuclear Physics program depends upon the existence and effective operation of large and complex accelerator facilities. These facilities provide the variety of projectile beams which are required for forefront nuclear research. Their capabilities determine which experiments can be performed and which cannot.

Seven existing accelerator facilities are operated by the Nuclear Physics program as national facilities. Beam time at these facilities is made available to all the Nation's scientists on the basis of scientific merit and technical feasibility. The national facilities are: the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory; the Bates Linear Accelerator Center at Massachusetts Institute of Technology; the SuperHILAC/Bevalac at Lawrence Berkeley Laboratory; the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory; the 88-Inch Cyclotron at Lawrence Berkeley Laboratory; the ATLAS facility at Argonne National Laboratory; and the Tandem/AGS Heavy Ion Facility at Brookhaven National Laboratory.

Each of the national facilities accommodates major university-based user group research programs. Typically, an outside user group plans experiments and fabricates detectors and other instrumentation at the home institution, executes and partially analyzes experiments at the national facility, and completes analyses and prepares material for publication at the home institution. Nuclear Physics directly supports 75 university-based user groups who conduct most or all of their research at these national facilities. To complement the national facilities, the Nuclear Physics program supports dedicated on-campus accelerators at Duke University, University of Washington, Yale University, and Texas A&M University.

Subprogram Structure

The Nuclear Physics program is divided into four subprograms: Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, and Nuclear Theory.

MEDIUM ENERGY NUCLEAR PHYSICS

The Medium Energy Nuclear Physics subprogram supports experimental nuclear research and accelerator facility operations at facilities capable of accelerating electrons or light ions (protons, deuterons, helium-3, and helium-4) to energies sufficient to produce pi mesons. In addition, this subprogram supports medium energy experiments at accelerators operated by other DOE and NSF programs and at unique foreign facilities. Research activities in the program range over a broad set of topics: properties of nuclei which can be learned from meson and lepton probes, the mechanisms by which mesons interact with nuclei, the fundamental weak and strong interactions, the fundamental symmetries of nature, distribution of electric and magnetic charge within nuclei, and the electromagnetic properties of nuclei.

Two national accelerator facilities are operated entirely under the Medium Energy subprogram--the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National laboratory and the Bates Linear Accelerator Center at the Massachusetts Institute of Technology. Operation of the Bevalac for acceleration of hydrogen and helium nuclei is also budgeted under this subprogram. In FY 1985, the accelerator at the Stanford Linear Accelerator Center (SLAC) began operations for nuclear physics research using the new off-axis source and injector. Costs of SLAC operation of the new injector for nuclear research are supported under the Medium Energy subprogram. These accelerator facilities serve a nationwide community of scientists from over 100 American institutions, of which over 90% are universities. Nearly all of the "outside user" groups receive direct project support for their research activities from either the Department of Energy or the National Science Foundation.

HEAVY ION NUCLEAR PHYSICS

In execution of the Heavy Ion research subprogram, nuclei are accelerated and then used as projectiles to bombard other nuclei. In such collisions, large quantities of energy, mass, and angular momentum are available for transfer between the colliding projectile and target nuclei. These collisions provide powerful probes of the properties of nuclei and nuclear matter under extreme conditions. Conduct of the Heavy Ion Nuclear Physics subprogram requires efficient and effective operation of accelerator facilities which, taken together, provide projectile nuclei varying in mass from lithium with 6 mass units to uranium with 238 mass units, and in energy from approximately 5 MeV per mass unit to 2000 MeV per mass unit (a mass unit is about the weight of one proton or neutron). To provide this wide variety of complementary nuclear probes, the Heavy Ion Nuclear Physics subprogram supports operations and research at five national laboratory-based accelerator facilities (SuperHILAC/Bevalac at Lawrence Berkeley Laboratory, Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory, Tandem/AGS Heavy Ion Facility at Brookhaven National Laboratory, 88-Inch Cyclotron at Lawrence Berkeley Laboratory, and the ATLAS facility at Argonne National Laboratory) and at three university-based accelerator facilities (Yale University, University of Washington, and Texas A&M University).

LOW ENERGY NUCLEAR PHYSICS

This subprogram emphasizes experimental investigations of nuclear structure, nuclear decay properties, and low energy reaction mechanisms and utilizes probes of polarized and unpolarized light ions, neutrons, and gamma rays. The generally smaller scale of Low Energy research facilities and instruments make research under this subprogram attractive for on-campus accelerator facilities. Low Energy research is rich in unsolved problems that demand instruments and experimental techniques of the highest precision and resolution--for example, experiments in which the nuclear spins of the interacting species are controlled or determined. To provide for the various types of beams used by the Low Energy Nuclear Physics subprogram, support for operations is provided at two national laboratory-based accelerator facilities (the 88-Inch Cyclotron at Lawrence Berkeley Laboratory and the ATLAS facility at Argonne National Laboratory) and at four university-based accelerator facilities (Duke University, Yale University, University of Washington, and Texas A&M University).

NUCLEAR THEORY

Theoretical nuclear research interprets the results of experiments in terms of fundamental theory and guides experiments by identification of those measurements which are most likely to yield definitive results. Thus, this subprogram is strongly interactive with the three (Medium Energy, Heavy Ion, and Low Energy Nuclear Physics) subprograms which are concerned with operation of facilities and execution of experiments. Major theoretical efforts are supported at the Massachusetts Institute of Technology, Argonne National Laboratory, Brookhaven National Laboratory, Los Alamos National Laboratory, Lawrence Berkeley Laboratory, and Oak Ridge National Laboratory--sites of the Nuclear Physics program's seven national accelerator facilities. In addition, the subprogram supports research at 30 universities across the Nation.

The basic goal of nuclear theory is to understand the diverse array of nuclear species and interactions which have been observed in terms of a few simple constituents and the fundamental forces of nature. Traditionally, the constituents of the many-bodied nucleus have been assumed to be the hadrons, i.e. neutrons, protons, and mesons. In recent years, elementary particle physics research has concluded that there is a substructure of the hadrons made up of quarks and gluons. Most recently, theories of nucleon-nucleon interactions have evolved from simple models where quarks are treated as interacting point particles to more exact relativistic field theories. Development and implementation of these relativistic field theories for nuclear physics is an important thrust of work in the Nuclear Theory subprogram.

ATLAS

Argonne National Laboratory
Argonne, Illinois

Description of Facility

The Argonne Tandem/Linac Accelerator System (ATLAS) consists of three components, each with its own associated experimental areas. Common to all components is the Model FN Tandem Van de Graaff (9 million volt terminal potential) which has the capability of accelerating both light and heavy ions. The second component is a prototype heavy ion superconducting linac with a 20 million volt equivalent potential drop which was developed and installed in 1981 after an intensive pioneering effort by the Argonne National Laboratory (ANL) staff. The prototype linac has an experimental area with a scattering chamber and a magnetic split-pole spectrometer. The third component, which was initiated as an FY 1982 construction project to be completed in 1985, is the ATLAS superconducting linac. It will raise the accelerating power of the tandem-linac system for heavy ions to the equivalent of a 50 million volt (terminal) tandem. Major research apparatus associated with the ATLAS accelerator are a multidetector gamma-ray spectrometer, a large general purpose scattering chamber, and a split-pole magnetic spectrograph.

Acquisition Cost

Existing tandem-linac: $13.0 million (distributed from FY 1961 to FY 1981)
Replacement cost is $18.0 million (FY 1983 dollars).

ATLAS Construction Project: (FY 1982, 1983) $7.7 million

Overview of Research Program

Heavy ion beams are used for studies of high-spin nuclear states, heavy ion induced resonances, fission and fusion reactions, quasi-elastic and deep inelastic reactions, and mass spectrometry. These studies are occasionally supplemented by measurements with light ion projectiles.

Fraction of Beam Time to Outside Users: 50%

Program Accomplishments

Scientists at Argonne have been instrumental in identifying the contributions of second-order collective excitations to the single-particle states made in transfer reactions. They have been leaders in the effort to understand the limits governing the fusion of two complex nuclei at intermediate energies. The dependence of incomplete fusion on projectile type and on mass asymmetry in the entrance channel have been established. They have contributed heavily to the investigation of resonance phenomena in di-nucleon quasi-molecular formation. Of special interest has been the work on collective states which investigates the way that nuclei deform, sometimes prolate and sometimes oblate, under the addition of large amounts of angular momentum. The prominence of quasi-elastic reaction channels and its influence on other reaction channels has been established for very heavy collision systems.

Future Directions

The addition of the prototype linac booster and, even more, the ATLAS construction project, is transforming the emphasis of the facility into one of host laboratory for outside users. In addition to continuation of the present programs, new work with visitors is beginning in the area of damped reactions with heavy ion projectiles. The study of high-spin nuclei will enter a new phase with a novel detection system being constructed in collaboration with the University of Notre Dame. Limits of nuclear stability with respect to angular momentum, excitation energy, and neutron-to-proton ratio will be explored with the new beams soon to be available. A complete characterization of the distribution of reaction strength in the energy range from well below to well above the Coulomb barrier will be attempted with the versatile, high-quality beams from ATLAS. Continuing effort will be devoted to the refinement and exploitation of the advanced technology on which ATLAS is based with emphasis on the development of superconducting RF resonators for cost-effective acceleration of very slow-moving ions.

PARAMETERS

Mass Range	1 to 130 atomic mass units (AMU)
Energy Range (Light Ions)	5 to 27 million electron volts (MeV)/AMU
Energy Range (Heaviest Ions)	1 to 5 MeV/AMU
Pulse Width	DC to 50 picoseconds
Energy Resolution	0.01% to 0.1%

TANDEM/AGS HEAVY ION FACILITY

Brookhaven National Laboratory
Upton, New York

Description of Facility

Construction is under way for a 2000 ft. tunnel and beam line to couple the Tandem Van de Graaff complex with the Alternating Gradient Synchrotron (AGS). Heavy ions up to mass 32 (sulphur) will be injected into the AGS and accelerated to 14 billion electron volts per atomic mass unit (14 GeV/AMU), 7 times higher than the heavy ion energies available at the Bevalac. The facilities and equipment necessary for this unique coupled operation are now under construction. The first experiments will begin in 1986.

The Brookhaven tandem facility consists of two model MP tandem electrostatic accelerators. In the coupled mode, they are equivalent to a single 20 million volt tandem. Accelerated ions of over 55 isotopes of 40 different elements are available for experiments. Coupled operation of the tandems in a unique accelerator-decelerator mode has provided very low energy, high-charge-state heavy ions for atomic physics studies. Experimental stations in three well equipped experimental areas include a variety of scattering chambers and a QDDD type magnetic spectrometer. A special eight-panel electrode system called a "portico intershield" was recently installed in one of the tandems in order to improve operational reliability at the 15 megavolt level necessary for injection into the AGS.

The Alternating Gradient Synchrotron began operation in 1958 for High Energy Physics, and today the primary mission of the AGS remains high energy physics research. The AGS provides 30 GeV protons for a wide ranging high energy physics research program carried out by scientists from all over the world. The addition of a new, lower frequency RF acceleration cavity will allow AGS preacceleration of the heavy ions from the tandems up to energies suitable for acceleration by the regular proton RF cavities.

Acquisition Cost

Tandem Facility	$30 million (1984 dollars)
Heavy Ion Transfer Line, Accelerator Modifications & Experimental Equipment	$17 million (1984 dollars)
AGS Facility	> $200 million (1984 dollars)

Overview of Research Program

Accelerated heavy ions at the tandem facility are used for research programs in heavy ion reactions, nuclear structure, and atomic physics. About 100 scientists and students perform research at the facility annually. Over 30 students from 8 universities have performed a major part of their graduate thesis work at the BNL tandem. A unique carbon-14 ion beam will provide new research capabilities at tandem energies. Other ions will be used to test detectors for the new relativistic research program. Atomic physics experiments will continue with the unique accel-decel capability of four-stage tandem operation in the study of quasi-molecular, combined atom x-rays and resonant electron transfer.

The research program at the Tandems will be significantly decreased during construction of the transfer line project. The major research effort at present is in the preparation of experimental equipment for the AGS program. A spectrometer designed to search for evidence of the formation of the quark-gluon plasma or quark matter by the collision of relativistic heavy ions with heavy targets like uranium is now under construction in collaboration with scientists from universities and other national laboratories. A heavy ion users group has been formed to coordinate the interest of users of the AGS heavy ions; 350 scientists from United States laboratories and from many foreign countries have applied for membership.

Fraction of Beam Time to Outside Users:

Tandem Accelerators about 70%   AGS (initially about 50%)

Program Accomplishments

Pioneering studies of heavy ion induced direct reactions encompassing inelastic scattering and particle transfer have led to a quantitative theory for the reaction mechanism. The gamma-ray spectroscopy of very high spin states in many new isotopes has led to a better understanding of how collective nuclear behavior changes over to independent particle behavior as higher spins and excitations are reached. The complex structure of back angle elastic scattering of heavy ions has been extensively studied at Brookhaven. High energy resolution studies of heavy ion radiative capture unexpectedly demonstrated that giant resonances, both quadrupole and dipole, could be built on highly excited nuclear states.

Future Directions

BNL has proposed to DOE's High Energy Physics program construction of a booster synchrotron for the AGS. It would inject the AGS with 2.5 GeV protons to increase the operating intensity about three fold and raise the polarized proton beam intensity. It would also accelerate ions from the tandem up to mass 200, extending the capability from sulphur to gold. This complex of Tandem-Booster-AGS would provide a full range of heavy ion beams for experiments at AGS energies (about 12 GeV/AMU) and could serve as the injector system for the proposed Relativistic Heavy Ion Collider (RHIC). RHIC would provide fixed target and colliding beams up to mass 200 with center-of-mass energies up to 100 GeV/AMU.

PARAMETERS

Tandem Accelerators	AGS
Mass Range - 1 to 238 AMU	Mass Range - 1 to 32 AMU
Energy Range - 0.5 to 13 MeV/A	Energy Range - 0.5 to 14 GeV/AMU
500 microsec pulse, 1 mA intensity	Intensity - about 10^9 (HI) particles/sec

CYCLOGRAAFF ACCELERATOR

Triangle Universities Nuclear Laboratory
Duke University
Durham, North Carolina

Description of Facility

The accelerator facility consists of a sector-focused cyclotron injecting negative light ions into an FN tandem Van de Graaff. The tandem can be operated without the cyclotron to provide protons and deuterons, polarized or unpolarized, to 17 million electron volts (MeV). When the cyclotron is used as an injector, unpolarized beams of protons up to 32 MeV and deuterons to 25 MeV can be produced. The Lamb shift polarized ion source, one of five ion sources at the Triangle Universities Nuclear Laboratory (TUNL), has recently been modified in order to produce a pulsed beam of polarized deuterons which, in turn, is used to create a pulsed beam of polarized neutrons for time-of-flight spectroscopy with two nanosecond resolution. Major pieces of experimental equipment include: (1) a large time-of-flight facility used to measure neutron elastic and inelastic scattering and to study the interaction of polarized and unpolarized neutrons with a wide range of nuclei; (2) two large gamma-ray spectrometers for radiative capture measurements; (3) VAX 11-780 and VAX 11-750 computer systems for data acquisition and analysis; and (4) a 7 milliKelvin, 7 Tesla cryogenic polarized target facility used in transmission experiments with polarized neutrons. The laboratory also includes an upgraded KN Van de Graaff which produces proton beams at 4 MeV with an energy spread of only 100 eV.

Acquisition Cost

$2.5 million	Cyclograaff (FY 1966)
1.5 million	Building (FY 1966)
2.0 million	Auxiliary Equipment

Replacement cost is approximately $20 million in FY 1984 dollars.

Overview of Research Program

TUNL is a highly successful collaborative effort of three major universities in North Carolina: Duke University at Durham, the University of North Carolina at Chapel Hill, and North Carolina State University at Raleigh. The research program concentrates on studies of nuclear processes using light ion and neutron projectiles which are polarized or unpolarized. The research program can be summarized as follows: (1) the study of nuclear resonances with high resolution proton beams to test a wide range of nuclear models; (2) the capture reaction program using high resolution NaI and BGO gamma-ray detectors to study giant dipole resonance and the few-body problems; (3) a program on fast neutron (8-17 MeV) scattering cross sections for elements important to the DOE magnetic fusion program; (4) a neutron polarization program to study spin-dependent effects in a variety of nuclear reactions; (5) a program using the polarized target with polarized fast neutrons to determine the spin-spin interaction in nuclei and reactions involving fundamental symmetries; and (6) a program using high resolution polarized proton and deuterons to study forbidden analog states and charge-symmetry-breaking processes.

Program Accomplishments

TUNL measurements of the fine structure of analog states and of amplitude correlations are unique. These are the only charged-particle data of sufficient quality to test new statistical theories and provide valuable information to complement neutron studies. These measurements have provided proton strength functions obtained from individual resonances. The charged-particle program has recently used polarized deuteron beams to initiate reactions which probe the nonspherical nature of the wave function for ^{4}He. On the tandem accelerator, an efficient three-stage bunching system has been constructed which facilitates measurements with pulsed, polarized beams. Up to 80% of the DC beam can be obtained in pulses on target with 2 ns burst width. A major achievement of the capture program in the past few years has been the production of high quality, polarized fast-neutron data, using this pulsing system, from which the collective E2 strength in the capture reaction can be deduced. In addition, Cyclograaff beams have been used to study the nature and properties of giant resonances built on highly excited states. The neutron program has provided neutron polarization information for the characterization of the spin-orbit interaction of neutrons with nuclei ranging from ^{1}H to ^{208}Pb. As a result, improved neutron-nucleus optical models have been developed to describe cross-section and polarization data over the 8-40 MeV range.

During the existence of this laboratory, 131 graduate students have earned Ph.D. degrees in experimental nuclear science. A large fraction of these are now in academic institutions and national laboratories. At present, some 29 graduate students are in residence at TUNL and working towards the Ph.D. degree.

Future Directions

A long range project is to develop an intense polarized ion source for injection into the cyclotron to produce polarized beams in a very useful higher energy range. Studies are under way to improve the efficiency of beam injection, acceleration, and extraction in the cyclotron as the first stage in our long range goal to produce high-intensity polarized beams over the entire 2-32 MeV energy range of the Cyclograaff. Work will also continue to further upgrade the beam pulsing system in order to obtain subnanosecond beam bursts on targets. Further long range plans include accelerator and facility upgrading to push the strong neutron physics program of the laboratory into measurements with multiple detector systems and long neutron flight paths.

PARAMETERS

Maximum polarized proton and deuteron energy	17 MeV
Maximum unpolarized proton energy	32 MeV
Maximum unpolarized deuteron energy	25 MeV
Pulse width	DC to 2 nanoseconds
Intensity (polarized beams)	200 nanoamperes on target
Intensity (unpolarized beams)	4 microamperes
Tandem beams available	$p, d, \vec{p}, \vec{d}$, ^{4}He, ^{3}He and heavier ions

SUPERHILAC/BEVALAC

Lawrence Berkeley Laboratory
Berkeley, California

Description of Facility

The proximity of two existing accelerators at Lawrence Berkeley Laboratory (LBL)--the SuperHILAC and the Bevatron--has permitted a combination of accelerator capabilities not available anywhere else in the world. This combined accelerator system, called the Bevalac, is operated as a national research facility for studies in nuclear and atomic physics, nuclear chemistry, and astrophysics. In addition, one-third of the Bevalac operating time supports biomedical research.

In 1974 the SuperHILAC (a linear accelerator capable of accelerating all elements to energies of 8.5 million electron volts per nucleon [MeV/AMU]) was connected by means of a beam transport line to the Bevatron, LBL's weak-focusing proton synchrotron. The SuperHILAC generates up to 36 pulses per second of 2 different ion species; thus, 2 pulses of gold might be sent to the synchrotron while 34 pulses of xenon are used locally for 2 separate experiments. Every six seconds, one of the pulses sent to the Bevatron is captured and further accelerated to energies up to 4.9 GeV for protons, 2.1 GeV/AMU for carbon, or 960 MeV/AMU for uranium. Both partially stripped ions (with charge-to-mass ratios as low as that of Au^{11+}) and fully stripped ions as heavy as uranium can be accelerated. In addition, the Bevatron's local injector, together with a fast-switching capability, allows nuclear science and biomedical experiments to be conducted concurrently.

The Bevalac's major detector facilities include: (1) HISS, a very large volume superconducting magnetic spectrometer system; (2) the Plastic Ball/Wall, a high-multiplicity detector with more than 100 detector elements; (3) TASS, a two-arm magnetic spectrometer system; (4) a pion detector system; (5) the Low Energy Beam Line (LEBL), designed for heavy ion experiments in the 40-200 MeV/AMU energy range; (6) a multipurpose projectile-fragment spectrometer; and (7) a magnetically surrounded streamer chamber providing photographs of heavy ion collisions. At the SuperHILAC, a new, on-line isotope separator (OASIS) has characterized many new isotopes, including proton emitters.

Acquisition Cost: Estimated replacement cost is $135 million (FY 1984 dollars).

Overview of Research Programs

Research interests pursued at the Bevalac include: (1) peripheral fragmentation reactions and studies of internal momentum; (2) nuclear reactions induced by beams of radioactive nuclei; (3) central collisions that create extremely hot, dense nuclear matter complexes; (4) production mechanisms of pions, kaons, hyperons, and antiparticles in nuclear matter; (5) searches for new forms of matter such as pion condensates and nuclear isomers; (6) searches for evidence of a quark-gluon plasma; and (7) searches for free quarks.

The SuperHILAC research program focuses on: (1) studies in heavy ion collisions of deep-inelastic reactions, fission, the limitations to fusion, and preequilibrium particle emission; (2) band structure and properties of high-spin states; (3)

discovery and characterization of new isotopes containing more than 100 protons; and (4) atomic physics of highly charged heavy atoms.

Fraction of Beam Time to Outside Users: SuperHILAC 50%, Bevalac 50%

Program Accomplishments

The Bevalac scientific program has been able to delve deeply into new regions of nuclear equations of state by making high-temperature compressed matter. Measurements have been made of the size of "hot spots" created when heavy nuclei collide. In addition, studies of nuclear collisions in which all (100 or more) secondary charged particles are characterized have revealed the phenomenon of collective energy flow--a phenomenon in which high pressures deflect many particles away from the beam direction. Other studies of central collisions of relativistic heavy ions have uncovered a puzzle in the production of mesons. Pions are produced several times less abundantly than predicted, but kaons are produced several times more copiously than expected.

The SuperHILAC has long been a world center for research with very heavy ion beams. The pioneering program in deep-inelastic scattering studies continues with a new generation of particle and gamma-ray detectors and coincidence experiments, and the relationship between the evaporation of particles and fission is also being explored. Electromagnetic moment measurements via Coulomb excitation and Doppler-shift techniques are providing stringent tests of today's nuclear models. Heavy-element isotopes and nuclei near the proton drip line are being studied with new isotope separators.

Future Directions

Bevalac programs will continue to use their improved detector systems to study correlations in the emissions from hot nuclei; in particular, dilepton emission will be examined. The production of exotic species in hot nuclear matter will be pursued by detecting antiprotons and short-lived rho mesons. Evidence for a transition from ordinary nuclear matter to a quark-gluon plasma will be sought. The SuperHILAC program will continue with increased emphasis on the heaviest projectiles. Explanations for the processes of equilibrating mass, energy, and charge in deep-inelastic reactions will be sought. Further developments in the atomic physics of highly charged heavy ions will be pursued as tests of QED and of relativistic effects. Experimenters are expected to take increasing advantage of the Bevalac's growing flexibility to produce beams of low-charge-state heavy ions, H-like and He-like ions, and unstable nuclei.

PARAMETERS

	Bevalac	SuperHILAC
Mass Range	1-238 AMU	1-238 AMU
Energy Range	4.9 GeV (protons) 35-2100 MeV/AMU (ions up to 50 AMU) 20-1000 MeV/AMU (heavier ions)	1.2-8.5 MeV/AMU (all ions)
Pulse Width	800 milliseconds	1 nanosecond microstructure 3-8 millisecond macrostructure
Energy Resolution	0.05%-0.1%	0.5%-1.0%
Beam Intensity	10^{6}-10^{10} particles per second	10^{11}-10^{12} particles per second

88-INCH CYCLOTRON

Lawrence Berkeley Laboratory
Berkeley, California

Description of Facility

The 88-Inch Cyclotron is operated as a national facility for experimental research in nuclear science and in applied areas such as biomedicine, surface physics, and radiation damage in semiconductors. The cyclotron can accelerate all ions from hydrogen through krypton to energies above the Coulomb barrier for targets as heavy as uranium. The recent completion of a high-charge-state Electron Cyclotron Resonance (ECR) ion source has greatly extended the available range of ions and energies. This ion source is the first of its type to operate in the United States and presently offers high-charge-state ions at intensities comparable to or exceeding the performance of other ECR sources throughout the world. The maximum energy for heavy ions is 140 MeV q^2/A, where q and A are the charge and mass of the accelerated ion, respectively. Polarized ions (protons and deuterons) are produced by a high-current atomic beam polarized ion source and are then accelerated to energies as high as 55 MeV.

There is a large complement of experimental equipment located in the experimental areas adjacent to the cyclotron. In particular, a new 21-element array of Compton-suppressed high-resolution germanium detectors has just come into use for studies of nuclei at high spin. There is also a large diameter scattering chamber, high resolution magnetic spectrometer, time-of-flight spectrometer and an on-line isotope separator for the study of exotic nuclei.

Acquisition Cost: Estimated replacement cost is $40.5 million (FY 1984 dollars).

Overview of Research Program

The basic research program is focused in four major areas: (1) investigation of heavy ion reaction mechanisms over a wide range of energies up to 35 MeV per atomic mass unit; (2) production and study of exotic nuclei far from stability; (3) structure of nuclei at high angular momentum; and (4) studies of spin-polarization effects and basic symmetry principles in nuclear interactions. In addition to the above, the cyclotron provides beams for the application of nuclear techniques to other areas of research including biology and medicine and the study of cosmic-ray damage to satellite electronic components.

Fraction of Beam Time to Outside Users: typically 25-30%

Recent Program Accomplishments

Recent research accomplishments include: (1) observation of a new radioactive decay mode--beta-delayed two proton emission from the exotic nuclei ^{22}Al and ^{26}P; (2) discovery of a giant dipole resonance built on highly deformed, high angular momentum states; (3) observation of nuclei with moments of inertia approaching the rigid-body value; (4) studies of the emission of heavy, complex fragments by highly excited nuclei; (5) the separation of transfer and breakup processes in heavy ion reactions utilizing a very large solid angle plastic scintillator array;

and (6) studies of the properties of the transfermium nuclei produced by heavy ion beams and a highly radioactive target of einsteinium.

Future Directions

Light ion beams will continue to be used for the production and study of new exotic nuclei and for testing fundamental symmetries. Heavy ion beams in the range of 10-35 MeV/AMU will permit an exploration of the transition region from fusion to fragmentation. Studies of the structure of nuclei undergoing rapid rotation will be pushed to spins approaching the fission limit. The development of new beams, including rare isotopes, will be made possible by the ECR source. Use of heavy ion beams for the testing of integrated circuits for susceptibility to cosmic ray damage will be increased to meet a national need in this area.

PARAMETERS

Mass Range	1-100 AMU (atomic mass unit)
Maximum Energy	
Protons	55 MeV
A = 4 - 20 AMU	35 MeV/AMU
A = 20 - 40 AMU	35-17 MeV/AMU
A = 40 - 100 AMU	17-4 MeV/AMU
Intensity	$10^{10}-10^{14}$ particles per second
Pulse Width	0.5-2 nanoseconds
Energy Resolution	0.03-0.3%
Macroscopic Duty Factor	100%

CLINTON P. ANDERSON MESON PHYSICS FACILITY (LAMPF)

Los Alamos National Laboratory
Los Alamos, New Mexico

Description of Facility

The LAMPF accelerator is a high-current, 800 million electron volt (MeV), proton linear accelerator about one-half mile in length. The primary proton beam intensity exceeds the sum of intensities of all other proton medium energy and high energy accelerators in the world. It is a source of up to 12 simultaneously operating secondary beams including neutrons, pions, muons, and neutrinos. Polarized and unpolarized beams of protons and neutrons of variable energy are also available. Major, permanent experimental facilities include high resolution proton and (charged and neutral) pion spectrometers. A large NaI detector array is in use to study rare decay modes of the muon and a time-projection chamber is being used to study normal muon decays. Other facilities include capability for isotope production and radiation effects studies. LAMPF also concurrently provides proton beams to the Weapons Neutron Research (WNR) Facility. WNR provides a pulsed spallation neutron source for materials research and for weapons research and development. A proton storage ring funded by Defense Programs and Basic Energy Sciences is under construction to extend the research capabilities of the WNR Facility by providing higher peak neutron fluxes.

Acquisition Cost

The original cost was $57 million during the construction period 1967-72. Development costs and subsequent additions, including beam lines, increased the direct outlay to $110 million. Present day replacement cost is estimated at more than $250 million.

Overview of Research Program

The four nuclear physics research areas of major emphasis at LAMPF are studies of: (1) nuclear structure by observing the interaction of pions with target nuclei; (2) mechanisms by which pions and protons react with nuclei; (3) the basic interaction between protons and protons, between neutrons and protons, and between pions and neutrons or protons; and (4) the fundamental weak interaction. Approximately 60 experiments--resulting in an average of 140 scientific publications--are completed in a typical year. LAMPF serves a large community of outside users with more than 430 scientists each year participating in the research program.

Fraction of Beam Time to Outside Users: 65%

Program Accomplishments

Recent research accomplishments at LAMPF include: (1) use of the pion charge exchange reactions to excite isotopic analog states, i.e., states of the nucleus showing strong symmetry between neutrons and protons; (2) discovery of an isotopic monopole giant resonance (i.e., neutron-proton breathing mode oscillation); (3) first observation of free muonium; (4) observation of the Lamb shift in muonium; (5) a stringent new limit on the rare decay, muon decaying to 3 electrons, namely

1×10^{-10}; (6) an experimental demonstration of the need for using the full Dirac wave function to describe polarized nucleon-nucleus scattering; and (7) evidence found with the pion double-charge-exchange reaction on ^{14}C at 50 MeV which showed that a six-quark cluster component is required in the nuclear wave function.

Future Directions

The LAMPF experimental program is emphasizing nuclear structure and nuclear reactions, studies of the weak interactions, and spin-dependent nucleon-nucleon and nucleon-nucleus scattering. Isotope production, materials science, and national security programs will continue to receive balanced support.

PARAMETERS

Primary Beams

Particle	
H^+	1000 microampere at 10.5% Duty Factor
H^-	Up to 100 microampere at variable Duty Factor
H^-	5 nanoampere at 3% Duty Factor with 80% polarization

(Dual energy operation is routine for H^- beam energies of 212 to 800 MeV and H^+ beam energy of 800 MeV; time sharing of duty factor is required.)

Secondary Beams

Particles	
pi^+, pi^-	Four beams; up to 10^9 pi^+/sec; 100-700 MeV/c
mu^+, mu^-	Two beams; more than 10^7 mu^+/sec; 0-250 MeV/c
p	Two beams; 650-1500 MeV/c
n	One beam; 600-1500 MeV/c
neutrino	Three beams; 20-150 MeV

These beams plus the WNR Facility can be operated simultaneously. In regular operation, LAMPF provides primary or secondary beam to 12 or more experiments simultaneously, not including those at WNR.

Spectrometer Systems

o High Resolution Spectrometer (HRS)	30-50 kiloelectron volts (keV) energy resolution; 2 milliradian (mrad) angular resolution; high efficiency focal plane polarimeter
o Energetic Pion Spectrometer (EPICS)	Channel 150 keV energy resolution; 10 mrad angular resolution; handles 10^8 pi^+/sec
o Pi-zero spectrometer	2 MeV energy resolution; large solid angle
o Clamshell (LEPS)	20-150 MeV pi's with 0.5 MeV resolution at 150 MeV

(Other permanent facilities are available at LAMPF, but these are the premier facilities of their type in the world.)

BATES LINEAR ACCELERATOR CENTER

Massachusetts Institute of Technology
Middleton, Massachusetts

Description of Facility

The Bates facility supplies very high quality electron beams with energies up to 750 million electron volts (MeV). The linear accelerator (202 meters in length) provides beams with energies up to 400 MeV for one pass of acceleration. A project to recirculate the electron beam through the accelerator for a second pass of acceleration and thereby increase its maximum energy to 750 MeV was completed in FY 1982. One experimental hall contains an energy-loss spectrometer system which sets the standard for high-resolution electron scattering studies of atomic nuclei. This capability is complemented by three medium resolution, large solid angle, broad-range magnetic spectrometers and a neutral pion spectrometer in a second experimental area.

Acquisition Cost

Original Facility	$ 7.2 million*	(1965-72)
Energy Loss Spectrometer System	$ 4.0 million	(1971-82)
Second Experimental Area	$ 5.0 million	(1977-79)
Major Equipment Additions	$ 5.0 million	(1978-82)
Recirculator	$ 1.8 million	(1980-81)

* Includes $1.5 million contribution by Massachusetts Institute of Technology.

Present day replacement cost is estimated at $55 million (in FY 1982 dollars).

Overview of Research Program

The Bates experimental program has centered on high-precision experiments which resolve complicated nuclear structures. Elastic and inelastic electron scattering experiments reveal the electromagnetic structure of nuclei, including contributions not only from protons and neutrons but also from the motion of charged mesons. An active intermediate energy, photonuclear program including photonucleon, photopion, and Compton scattering experiments probes the short-distance structure of nuclei and the nuclear interactions of nucleon excited states. Deep inelastic electron scattering is used to understand the nuclear single-particle response. A growing program of coincidence measurements is addressing a variety of important questions including nuclear collective motion at high excitation energy, nuclear reaction mechanisms, and fundamental properties of few-nucleon systems.

Fraction of Beam Time to Outside Users: 60%

Program Accomplishments

Recent research achievements include: (1) stringent tests of nuclear mean field theories by precision measurements of electromagnetic structure near closed shells and by the systematic study of nuclear stretched states (elementary excitations resulting from the maximum possible angular momentum transfer in a one-step process); (2) demonstration of the importance of meson exchange currents in the nucleus, particularly in the short distance structure of nuclear magnetization; (3) measurements of the nuclear response functions at large energy transfer resulting in total strengths unexplainable in the conventional framework of static nucleons; (4) measurement of the nuclear interaction of the lowest nucleon excited state (the delta) by means of coherent photoproduction of neutral pions, photon scattering, and deep-inelastic electron scattering; (5) studies of the mechanism for pion production in nuclei; and (6) (e,e'p) coincidence studies of proton knockout which demonstrate the importance of multinucleon contributions to the electromagnetic current.

Future Directions

The higher electron energy now available through recirculation and the recently constructed magnetic spectrometers will broaden the research program significantly, including a variety of coincidence measurements. Changes to the RF system are being implemented which should increase the maximum beam energy to approximately 1 GeV in 1986. A polarized electron source will be available in 1985, permitting a study of the semileptonic, neutral, weak current and other new tests of nuclear models. A high-flux photon facility will be completed in 1985 permitting, among other studies, high-resolution photoneutron studies. Construction of a pulse stretcher ring and internal target hall has been proposed. This upgrade would lead to a duty factor of 85% and thus would permit a broad range of intermediate energy coincidence experiments. The proposed internal target hall would provide the opportunity for an exciting program of electronuclear studies with polarized targets.

PARAMETERS

Primary Electron Beam

Maximum Operating Energy (Single Pass) - 400 MeV
Maximum Operating Energy (Recirculated) - 750 MeV
Beam Current - 100 microamperes (30 microamperes when recirculated)
Energy Spread - more than 80% of current within 0.3%
Beam Emittance at Maximum Energy - 2×10^{-6} rad-cm
Duty Factor - 0.5%

Spectrometers

Designation	Solid Angle	Momentum Acceptance	Resolution
Energy Loss	5.4 MSR	10%	4×10^{-5}
Medium Energy Pion	30.0 MSR	20%	5×10^{-4}
One Hundred Inch Proton	20.0 MSR	16%	5×10^{-4}
Big Bite	2.0-15.0 MSR	50-10%	$10^{-3} - 10^{-2}$
Pi-zero	0.5 MSR	15%	10^{-2}
Parity	40.0 MSR		7×10^{-2}

HOLIFIELD HEAVY ION RESEARCH FACILITY

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Description of Facility

The Holifield Heavy Ion Research Facility is a major national user facility for research in the field of heavy ion nuclear physics. The facility includes a 25 million volt (MV) electrostatic tandem accelerator and the Oak Ridge Isochronous Cyclotron (ORIC). First nuclear research experiments with the 25 MV folded tandem, the world's largest accelerator of this type, were in 1981. The ORIC cyclotron, first placed in operation in 1963, was modified to serve as a booster accelerator. The tandem and ORIC, operating separately or as a combined system, provide the widest range of projectile species and precision energies of any facility in the world.

In addition to the normal complement of experimental equipment, Holifield has been equipped with two magnetic spectrometers, a velocity filter, a 5 ft. diameter scattering chamber, and a 72 element, large solid angle gamma-ray spectrometer. The UNISOR (University Isotope Separator - Oak Ridge) magnetic isotope separator project, which includes a laser and helium jet transport system, is located at Holifield and is jointly supported by the Department of Energy and 12 universities.

Adjoining Holifield are the buildings for the Joint Institute for Heavy Ion Research, a joint venture of the Oak Ridge National Laboratory, the University of Tennessee, and Vanderbilt University. Its mission is to promote research at Holifield by providing support to outside users.

Acquisition Cost

Cyclotron	$ 4.8 million (FY 1963)
Folded Tandem	$18.0 million (FY 1976)
Estimated Facility Replacement	$48.0 million (FY 1982 dollars)

Overview of Research Program

Heavy ion projectiles are used to study nuclear structure and nuclear behavior under a variety of extreme conditions such as high-excitation energy, large angular momentum, and mass far from the valley of stability. Information is gathered on nuclear shapes, level properties, collective and single-particle configurations of nuclei, and modes of decay. Nuclear reactions and the dynamical process by which they take place are explored as a function of energy and impact parameter. The type of reactions include fusion, fission, incomplete fusion, deep inelastic collisions, fragmentation, and quasi-elastic processes. In addition, there are smaller research programs in atomic physics and applications of nuclear science.

Fraction of Beam Time to Outside Users: 50%

One hundred twenty outside users participated in at least one experiment at Holifield during the past year.

Program Accomplishments

Changes in nuclear shapes, the role of rotational alignments, and the crossing of bands have been established through studies of discrete high-spin states and states in the continuum that are populated in both compound nuclear and transfer reactions. Lifetimes measured for the discrete states are especially important in determining their character. Isomer shifts and quadrupole and magnetic moments have been determined for the ground and isomeric states of short-lived Tl nuclei from the hyperfine structure resulting from laser-induced optical pumping. Gamma-ray decay branches have been measured from the giant quadrupole resonance in ^{208}Pb and provide, for the first time, microscopic composition of the resonance. The sharing of excitation energy among fragments has been explored under varying conditions between the two extremes of equal energy and of temperature equilibration. Evidence for a localized hot source in the nucleus has been established from small angle p-p correlations and from spectra of energetic protons and neutrons emitted in heavy ion induced reactions. The decrease of fusion cross section and corresponding increase in incomplete fusion channels have been studied as a function of energy and correlated with the impact parameter and entry channel. Lifetimes of reaction processes around 10^{-18} seconds have been measured through blocking of emitted particles by crystal lattices. Observation of neutral pi mesons at projectile energies of 25 MeV/AMU (the lowest energy to date for production of pions) has established the importance of cooperative action of many nucleons.

Future Directions

Investigation of nuclei at still higher temperatures and spin will become possible with completion of a BGO Compton-suppressed Ge detector system that will be incorporated into the Spin Spectrometer. A nuclear polarimeter now being planned for UNISOR will make it possible to establish nuclear spins and magnetic moments for levels in nuclei far from the valley of beta stability. Studies of reaction processes and their dynamics will continue; current questions of interest concern subbarrier fusion cross sections, division of excitation energy among ejectiles, entrance channel effects, time scale of reaction processes, effect of nuclear shapes on cross sections, and evolution of nuclear shapes during fission. Experimental apparatus will increase in sophistication to measure more of the ejectiles emitted in a given event. The special capabilities at Holifield for high energy resolution and ease in energy variability will be utilized to study giant resonances and transfer and inelastic scattering reactions.

PARAMETERS

Mass Range	11-238 atomic mass units (AMU)
Energy Range (Light Ions)	5-25 MeV/AMU
Energy Range (Heaviest Ions)	1-6 MeV/AMU
Intensity	10^{11}-10^{13} particles per second
Pulse Width	DC-1 nanosecond
Energy Resolution	0.01-0.3%

TEXAS A&M CYCLOTRON

Cyclotron Institute
Texas A&M University
College Station, Texas

Description of Facility

The Texas A&M Cyclotron is a sector focusing, variable energy cyclotron capable of accelerating protons to energies as high as 55 million electron volts (MeV), deuterons to 65 MeV, and ^{3}He and alpha particles to 130 MeV. Intense beams of polarized protons and deuterons can be generated. Over 40 species of heavy ion beams are currently available for both nuclear and atomic physics research with energies as high as 30 MeV per atomic mass unit down to less than 1 MeV per atomic mass unit. The cyclotron has an energy constant of 147. Major items of ancillary equipment include a high resolution, split-pole magnetic spectrograph; high resolution and high multiplicity gamma-ray detector systems; fully automated, large scattering chambers; and two VAX 11/780 computer systems for data acquisition and analysis.

Acquisition Cost

In 1965	$1.0 million	Robert A. Welch Foundation
	2.0 million	Texas A&M University
	3.0 million	Atomic Energy Commission
	$6.0 million	

Replacement value is $25 million (FY 1982 dollars).

Overview of Research Program

A broad-based program in basic and applied nuclear and atomic science is carried out at the Cyclotron Institute. Polarized and unpolarized light-ion beams are used to explore parity violation in the hadronic weak interaction, to measure the masses of exotic nuclei, to investigate structure of giant resonances in nuclei, and to determine properties of few nucleon systems. Heavy ion beam experiments focus on the mechanisms of heavy ion induced nuclear reactions and on the properties of nuclei with high excitation energies and high angular momenta, e.g., the structure of high spin states, cluster configurations in nuclei, nuclear deformations, limits to the existence of nuclei, and subthreshold pion production. Inner-shell vacancies in atomic electron states produced by high energy, heavy ion collisions are investigated by high resolution x-ray spectroscopy. Techniques are being explored and improved for identifying amounts and distributions of ultra-small quantities (about 10^{-12} grams per gram of sample) of impurities in matter through analysis of radiation from heavy ion bombardment.

Program Accomplishments

Texas A&M scientists have conducted an extensive series of high precision studies of giant resonance states in nuclei. From these experiments, giant monopole resonances (the entire nucleus contracts and expands as a unit) and their possible splitting have been identified and measured providing new and unique information about nuclear compressibility. In a systematic study of nuclear stability, the masses of nuclei near the limits of particle stability have been determined and the need for a charge-dependent nuclear force demonstrated. Experimenters at Texas A&M have demonstrated that "massive transfer" (a large part of the projectile transfers to the target) occurs quite generally in heavy ion reactions and populates nuclear states within a narrow angular momentum window, providing a new tool for nuclear spectroscopy. Studies of x-ray emission in heavy ion collisions have demonstrated the importance of fast electron rearrangement in highly ionized atoms and have led to the discovery of a resonant electron transfer process in ionic solids. The protocol for treatment of human cancer with neutron therapy was established in a program which treated over 500 patients in an 8 year period. Texas A&M scientists were the first to obtain quantitative determination of oxygen and boron at the 10^{-11} grams per gram of sample and 10^{-13} grams per gram of sample levels, respectively, using charged particle activation analysis and the first to profile gold by means of heavy ion backscattering. The Cyclotron Institute has been a significant source of scientific manpower with 45 students receiving Ph.D. degrees and 23 receiving M.S. degrees from cyclotron-based research from 1970 to 1984. Fifty-four scientists received their postdoctoral training during the same period.

Future Directions

A K=500 superconducting cyclotron is under construction (funded from State of Texas and Welch Foundation sources) with completion expected in 1986. It will serve alone as a source of high energy, light, and light-heavy ions and as an injector for the existing cyclotron for heavier ions. In addition to the present beams, the completed facility is expected to provide beams of 160 MeV deuterons and 320 MeV alpha particles and heavy ion beams up to 60 MeV/AMU for nuclei less than 20 AMU; up to 40 MeV/AMU for nuclei in the 20 to 40 AMU range; and up to 8 MeV/AMU for nuclei as massive as 136 AMU. Research priorities will include studies of simple modes of nuclear motion (giant resonances, molecular states), investigation of the dynamics of collective motion in heavy ion collisions, properties of nuclear matter at high temperature, and studies of fundamental forces in nature (parity violation, weak currents).

PARAMETERS

Present Cyclotron

Protons	55 MeV
Deuterons	65 MeV
^{4}He	130 MeV
^{12}C	26 MeV/AMU
^{40}Ar	8 MeV/AMU

Coupled Cyclotrons (expected performance)

Mass Ranges	1	to	136	AMU
Energy Range (Light Ions)	1.5	to	35	MeV/AMU
Energy Range (Heavy Ions)	0.5	to	8	MeV/AMU
Intensity	10^{11}	to	10^{14}	particles per second

TANDEM/SUPERCONDUCTING BOOSTER ACCELERATOR

Nuclear Physics Laboratory
University of Washington
Seattle, Washington

Description of Facility

The Tandem/Superconducting Booster Accelerator consists of two major components: (1) a Model FN Tandem Van de Graaff Accelerator and (2) a superconducting "booster" linear accelerator presently under construction. The tandem can operate at terminal potentials above 9 million volts and is capable of stand-alone operation or of serving as an injector for the booster. When completed in 1987, the booster will have an equivalent DC acceleration capability of about 26 MV. The tandem/booster system will have the capability of accelerating light ions as well as heavy ions (up to about 60 atomic mass units). The facility will provide 38 MeV protons, 72 MeV alphas, 106 MeV ^{6}Li, and will also provide light heavy ion beams at energies up to about 16 MeV per atomic mass unit.

In addition to these major components, the Nuclear Physics Laboratory also includes a PDP-11/60 on-line data collection system, a VAX-11/780 data analysis system, a large solid-angle momentum filter which has recently come into operation, and a high-current polarized ion source now being installed. The latter will produce microampere-level beams of polarized protons and deuterons at energies up to about 18 MeV when accelerated with the tandem alone and about 38 MeV when accelerated with the tandem/booster system.

Acquisition Cost

Tandem and Beam Lines	\$ 2.5 million (FY 1961, NSF)
Building	\$ 1.1 million (FY 1961, State of Washington)
Computer System	\$ 0.3 million (FY 1979, DOE)
Momentum Filter	\$ 0.2 million (FY 1980, DOE)
Polarized Source	\$ 0.5 million (FY 1982, DOE)
Booster Linac	\$ 8.0 million (FY 1984-85, DOE)
	\$ 1.0 million (FY 1984, State of Washington)
Estimate of Total Replacement Cost	\$22.0 million (FY 1984 dollars)

Overview of Research Program

The nuclear research program is very broad. It has recently included investigations of fundamental symmetries, the excitation of giant resonances, heavy ion reactions, and topics in nuclear astrophysics.

Program Accomplishments

Recent difficult and innovative experiments include studies of the weak nucleon-nucleon and electron-nucleon force by nuclear and atomic parity mixing, of nucleon charge conservation, and of the breakdown of isospin symmetry in nuclei. High precision investigations of deviations from Rutherford scattering in sub-Coulomb heavy ion scattering have permitted the observation of the dynamic effects of relativistically invariant wave equations as well as the effects of electron screening and dynamic nuclear polarization. Other examples of recent research include the study of the effect on atomic ionization of "time delay" in nuclear reactions, evidence which indicates the absence of the "low l-value window" predicted in heavy ion fusion reactions, and the demonstration that back-angle analyzing powers observed in the inelastic scattering of polarized protons to the continuum arise from orbiting.

Future Directions

The momentum filter which has recently become operational is being used for investigations of reaction processes at very forward angles and reactions with very small cross sections. A high-pressure helium polarimeter will soon be added to the instrument for use in investigations of depolarization, polarization transfer, and tests of time reversal invariance. The new polarized ion source, when installed, will make possible improved studies of giant resonance phenomena and of parity nonconservation in nuclear processes. The increased energy which will be made available when the booster becomes operational will open up a rich range of experimental possibilities for both light ion and heavy ion reactions. Among possible light ion investigations are studies of parity violations, radiative capture, resonance excitation and decay, continuum spectra, and reaction mechanisms. Among possible heavy ion investigations are studies of rapidly rotating nuclei, elastic and quasielastic processes, preequilibrium processes, deeply inelastic processes, and fusion and topics relevant to nuclear astrophysics.

PARAMETERS

Beam Type	Energy (MeV)* Tandem	Energy (MeV)* Tandem/Booster
Protons	18.0	37.6
Deuterons	18.0	40.6
Alphas	27.0	73.2
^{6}Li	36.0	105.6
^{12}C	54.0	194.4
^{16}O	63.0	254.4
^{28}Si	72.0	338.8
^{40}Ca	80.0	388.0
^{56}Fe	90.0	392.0

* Stated energies assume 9.0 MV terminal voltage on the tandem, 3.0 MV/m accelerating field on each of 36 resonators in the booster, and ions stripped twice to the most probable charge state.

TANDEM VAN DE GRAAFF ACCELERATOR

A. W. Wright Nuclear Structure Laboratory
Yale University
New Haven, Connecticut

Description of Facility

The first of the MP class tandem accelerators was installed at Yale in 1966 and operated at a terminal potential of 10 million volts (MV); subsequent improvements have raised this level to 13.5 million volts. Over 75% of the running time of this accelerator is devoted to acceleration of heavy ions--from ^{6}Li to ^{93}Nb. The accelerator will be removed from operation from June 1985 to May 1986 to permit completion of its conversion to the first of the ESTU class of tandems operating at terminal potentials up to 22.5 million volts.

A 4 MV single-ended Van de Graaff accelerator is currently under installation in the vault previously occupied by Yale's 70 MeV electron accelerator, and a 300 kV high-current implanter accelerator completes the accelerator complement of the laboratory.

Major research instrumentation includes an IBM 4341-based data acquisition and analysis system; a 23-gap magnetic spectrograph; a large solid angle single-gap magnetic spectrograph; a precision, computer-controlled goniometer carrying large gamma radiation detectors; an anticoincidence-shielded 30 cm x 30 cm NaI gamma-ray absorption spectrometer; a high precision x-radiation spectrometer system with Be windows; an ultra high vacuum ($<10^{-10}$ Torr) target station for beam-solid studies; an electrostatic mass separator for ultrasensitive mass spectrometry; and miscellaneous target chambers and detector systems. Nanosecond beam pulsing is being installed as part of the MP-ESTU conversion project.

Acquisition Costs

In 1963, the original costs were: accelerator--$3.1 million, ancillary equipment--$2.0 million, building and facilities--$1.9 million, totalling $7.0 million. Between 1963 and 1983, additional instrumentation costing approximately $3 million was acquired and $600,000 was expended in 1974 in upgrading the MP terminal potential from 10 to 13 MV. The present conversion to ESTU status will cost $11 million. Replacement cost of the facility, in FY 1985 dollars, would be approximately $40 million.

Overview of Research Program

The Wright Nuclear Structure Laboratory continues a broad program of study of nuclear phenomena ranging from the most fundamental to highly applied research and encompassing the interfaces with a number of other sciences such as astrophysics, particle physics, atomic physics, and surface science. In nuclear physics, recent emphasis has been on search for the dynamic symmetries and simplicities underlying nuclear structure and dynamics, on study of the response of nuclear systems to extreme centrifugal stress, and on entirely new collective and molecular phenomena in the nuclear many-body system. Quantum electrodynamics is being tested in the zero momentum limit in atomic studies with supercritical fields. Fundamental studies on geophysical systems of several millions of years in age are in progress as are studies on the mechanisms of sputtering and adhesion critical to all present and future large-scale electronic device integration.

Program Accomplishments

Recently, the laboratory reported: experimental evidence for the first supersymmetry observed in nature centering on ^{193}Ir; an entirely new form of dipole nuclear collectivity; a spectrum generating algebraic approacn to the understanding of nuclear molecular interactions; nuclear astrophysical cross sections pertinent to the formation of the solar system; and emission of monoenergetic positrons in supercritial Coulomb fields.

In applied areas, fundamental new information on the physics of the sputtering process induced by both keV and MeV beams has been reported as well as new techniques for beam induced adhesion of thin films, contacts, and the like, of importance in microelectronics. The quantitative, nondestructive characterization of hydrogen in solids that was reported several years ago has been further refined for use in many areas of technology including fusion energy research.

For more than 20 years, Yale has graduated more Ph.D.'s in experimental nuclear physics than any other institution in the world. Currently, 31 graduate students are working in the Wright Laboratory.

Future Directions

Extension of symmetry and group theoretical concepts in the study of both nuclear structure and dynamics will continue as an active research area, so also, will study of nuclear molecular phenomena, now shown to be a general feature of nuclear interactions. Study of supercritical Coulomb field phenomena will now focus on nuclear aspects of the interaction using monoenergetic positrons as coincidence labels for interesting events. Nuclear astrophysics and geophysics will continue as important parts of our program as will applied studies in the area of beam solid and beam surface interactions. Four new beam lines are being added to the facility to accommodate the anticipated increased number of external users and collaborators wishing to exploit the ESTU characteristics.

PARAMETERS

BEAM	Energy (MeV)*	
	MP	ESTU
Protons and deuterons	27 MeV	45 MeV
^{6}Li	55 MeV	90 MeV
^{93}Nb	260 MeV	540 MeV
^{120}Sn	250 MeV	590 MeV
^{208}Pb	---	650 MeV

* Assumes double foil stripping, terminal and columns.

STATISTICAL INFORMATION

National Facilities

BEAM HOURS FOR RESEARCH[1/]

	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
Clinton P. Anderson Meson Physics Facility	3650	3350	3900	3520	3100
LBL SuperHILAC/Bevalac	3475	3628	3097	3445	2201
Bates Linear Accelerator Center	3252	2944	3069	2992	3165
Holifield Heavy Ion Research Facility	1490	2264	2346	1980	1980
LBL 88-inch Cyclotron	4311	4297	4346	4510	4164
Argonne Tandem/Linac	4860	2660	2657	2460	2964
BNL Double MP Tandem	4860	6620	7188	6312	4032

	FY 1982	FY 1983	FY 1984	FY 1985
Clinton P. Anderson Meson Physics Facility	3095	3153	3846	2850
LBL SuperHILAC/Bevalac	1886	3083	3979	3500
Bates Linear Accelerator Center	1620	2109	2457	2500
Holifield Heavy Ion Research Facility	1525	3249	3177	4000
LBL 88-Inch Cyclotron	3609	3445	3368	3500
Argonne Tandem/Linac	3077	3279	4051	2500
BNL Double MP Tandem	5180	5700	4800	1920

[1/] "Beam Hours for Research" is the total hours the facility is in operation for the purpose of actually delivering beam for research use. This excludes time for tuning, machine studies, and shutdowns.

NUCLEAR PHYSICS PROGRAM

(Obligations in Millions of Dollars)

Operating Expenses	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
Medium Energy Nuclear Physics[1/]	$ 32.9	$ 33.7	$ 37.9	$ 41.3	$ 46.0
Heavy Ion Nuclear Physics	29.4	31.6	33.0	35.5	38.1
Low Energy Nuclear Physics	9.1	9.3	10.1	11.4	11.5
Nuclear Theory	4.9	5.4	6.1	6.1	7.0
Subtotal	$ 75.8	$ 80.0	$ 87.1	$ 94.3	$102.6

	FY 1982	FY 1983	FY 1984	FY 1985
Medium Energy Nuclear Physics[1/]	$ 52.6	$ 58.6	$ 64.6	$ 74.6
Heavy Ion Nuclear Physics	41.8	39.9	46.8	49.5
Low Energy Nuclear Physics	12.3	12.3	12.9	13.5
Nuclear Theory	7.7	8.1	8.9	9.3
Subtotal	$114.4	$118.9	$133.2	$146.9

[1/] Includes $2.0 million in FY 1982, $3.0 million in FY 1983, $3.0 million in FY 1984, and $3.1 million in FY 1985 which were provided under Defense Programs for LAMPF facility operations.

Capital Equipment	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
Nuclear Physics	$ 5.6	$ 7.0	$ 7.8	$ 8.7	$ 9.9

	FY 1982	FY 1983	FY 1984	FY 1985
Nuclear Physics	$ 9.5	$ 10.4	$ 11.3	$ 12.7

Construction

	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
Accelerator Improvement Projects	$ 1.3	$ 1.9	$ 1.5	$ 1.6	$ 1.6
General Plant Projects	4.4	2.7	2.9	3.0	2.8
Bates Second Expt. Area	5.0	0.0	0.0	0.0	0.0
LBL Uranium Beams Project	0.0	0.0	6.0	0.5	0.0
LAMPF Staging Area	0.0	0.0	0.0	2.4	0.0
Bates Recirculator	0.0	0.0	0.0	1.8	0.0
Michigan State SC Cyclotron*	0.0	0.0	0.0	5.0	6.9
Subtotal	$10.7	$ 4.6	$10.4	$14.3	$11.3

	FY 1982	FY 1983	FY 1984	FY 1985
Accelerator Improvement Projects	$ 1.5	$ 1.8	$ 3.5	$ 3.5
General Plant Projects	2.0	2.3	2.2	3.5
LAMPF Staging Area	0.0	-0.2	0.0	0.0
Bates Recirculator	0.0	0.1	0.0	0.0
ATLAS	4.0	3.7	0.0	0.0
Michigan State SC Cyclotron*	4.5	0.0	0.0	0.0
University Accelerator Upgrade	0.0	0.0	8.0	11.0
Brookhaven Transfer Line	0.0	0.0	5.0	5.3
	$12.0	$ 7.7	$18.7	$23.3

* Transferred to the National Science Foundation on October 1, 1982.

Total Nuclear Physics Program

	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
Total	$ 92.1	$ 91.6	$105.3	$117.3	$123.8

	FY 1982	FY 1983	FY 1984	FY 1985
Total	$135.9	$137.0	$163.2	$182.9

The Operating Expenses budget may also be broken down into functional activities:

	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
Operating Expenses					
Experimental Nuclear Research	$ 29.7	$ 32.0	$ 35.2	$ 40.4	$ 43.6
Theoretical Nuclear Research	4.9	5.4	6.1	6.1	7.0
Accelerator Facility Operations[1]	41.2	42.6	45.8	47.8	52.0
	$ 75.8	$ 80.0	$ 87.1	$ 94.3	$102.6

	FY 1982	FY 1983	FY 1984	FY 1985
Experimental Nuclear Research	$ 49.6	$ 47.5	$ 54.9	$ 59.7
Theoretical Nuclear Research	7.7	8.1	8.9	9.3
Accelerator Facility Operations[1]	57.1	63.3	69.4	77.9
	$114.4	$118.9	$133.2	$146.9

1/ Includes $2.0 million in FY 1982, $3.0 million in FY 1983, $3.0 million in FY 1984, and $3.1 million in FY 1985 provided under Defense Programs for LAMPF facility operations.

ACCELERATOR FACILITY STARTING DATES

	Construction* Start	First Experiment
Argonne Tandem/Linac		
Tandem	1959	1961
ATLAS Project	1982	1985
Brookhaven Double MP Tandems		
Tandems	1965	1969
Transfer Line Project	1984	1986
Duke University		
Cyclograaff Accelerator	1966	1968
SuperHILAC/Bevalac		
Linear Accelerator	1954	1957
Transfer Line Project	1973	1974
88-Inch Cyclotron	1958	1963
Clinton P. Anderson Meson Physics Facility (LAMPF)	1967	1972
Bates Linear Accelerator	1966	1974
Holifield Heavy Ion Research Facility		
Cyclotron	1959	1963
Tandem	1974	1981
Texas A&M Cyclotron	1964	1967
University of Washington		
Double FN Tandems	1961	1967
Superconducting Booster	1983	1987
Yale University		
MP Tandem	1962	1966
ESTU Upgrade	1984	1986

* Calendar year of directive to proceed with construction or of initial contract or grant for construction.

REPORT BY THE U.S.

General Accounting Office

DOE's Physics Accelerators: Their Costs And Benefits

This report provides an inventory of the Department of Energy's existing and planned high-energy physics and nuclear physics accelerator facilities, identifies their associated costs, and presents information on the benefits being derived from their construction and operation. These facilities are the primary tools used by high-energy and nuclear physicists to learn more about what energy and matter consist of and how their component parts or particles are influenced by the most basic natural forces.

Of DOE's $728 million budget for high-energy physics and nuclear physics during fiscal year 1985, about $372.1 million is earmarked for operating 14 DOE-supported accelerator facilities coast-to-coast. DOE's investment in these facilities amounts to about $1.2 billion. If DOE's current plans for adding new facilities are carried out, this investment could grow by about $4.3 billion through fiscal year 1994. Annual facility operating costs will also grow by about $230 million, or an increase of about 60 percent over current costs. The primary benefits gained from DOE's investment in these facilities are new scientific knowledge and the education and training of future physicists. According to DOE and accelerator facility officials, accelerator particle beams are also used in other scientific applications and have some medical and industrial applications.

GAO/RCED-85-96
APRIL 1, 1985

UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

RESOURCES, COMMUNITY,
AND ECONOMIC DEVELOPMENT
DIVISION

B-217863

The Honorable J. Bennett Johnston
Ranking Minority Member
Subcommittee on Energy and
  Water Development
Committee on Appropriations
United States Senate

Dear Senator Johnston:

This report responds to your request dated November 25, 1984. It includes information on the Department of Energy's high-energy physics and nuclear physics accelerator facilities, how much they cost, and what benefits are resulting from their construction and operation.

Unless you publicly announce its contents earlier, we do not plan to distribute this report further until 7 days after its publication date. At that time, we will send copies to other interested committees, members of Congress, and the Department of Energy. Copies will be made available to others upon request.

Sincerely yours,

Ralph V. Carlone for
J. Dexter Peach
Director

REPORT BY THE U.S. GENERAL
ACCOUNTING OFFICE TO THE
HONORABLE J. BENNETT JOHNSTON,
RANKING MINORITY MEMBER,
SUBCOMMITTEE ON ENERGY AND WATER
DEVELOPMENT, SENATE COMMITTEE ON
APPROPRIATIONS

DOE'S PHYSICS ACCELERATORS: THEIR COSTS AND BENEFITS

DIGEST

During fiscal year 1985, the federal government is providing about $820 million in support of high-energy physics and nuclear physics research. About $728 million, or nearly 90 percent of this amount, is being provided by the Department of Energy (DOE), and the remaining support is being provided by the National Science Foundation. (See pp. 7 to 9.)

Both high-energy physics and nuclear physics are exploratory fields of basic science in which experimental and theoretical studies are conducted. Generally, high-energy physics is aimed at determining what energy and matter ultimately consist of, ascertaining how the component parts (or particles) of matter interact with each other, and understanding the interrelationships between the most basic forces of nature[1] and the effects of these forces on matter. Nuclear physics concentrates on acquiring a better understanding of the atom's nucleus.

Most experiments in both high-energy physics and nuclear physics depend on machines called accelerators (also known as "atom smashers") that produce and accelerate beams of particles such as protons and electrons. These particle beams are made to collide with particles contained in various target materials or in other accelerated beams.

By analyzing these collisions, physicists are able to "see" the inner structure of the atom and its component parts. In this sense, the accelerator is analogous to a super microscope that enables physicists to study the substructure of submicroscopic nuclear particles. As the particles become smaller, or more elementary, they are bound together more tightly thereby requiring larger, more powerful, and complex accelerators. Because of their complexity, these accelerators also can be very costly. (See pp. 1 to 6.)

---

[1] The electromagnetic, weak nuclear, strong nuclear, and gravitational forces. (See pp. 2 and 3.)

WHY THE REVIEW WAS MADE

In his letter to GAO dated November 25, 1984, Senator J. Bennett Johnston, Ranking Minority Member, Subcommittee on Energy and Water Development, Senate Committee on Appropriations, stated that DOE's plans to build two new accelerators have increased the subcommittee's concern about the need for larger, more costly nuclear physics and high-energy physics facilities.

The first is a nuclear physics accelerator known as the Continuous Electron Beam Accelerator Facility, which DOE plans to locate at Newport News, Virginia. While not firm, DOE's current estimate for this accelerator--if approved by the Congress--is about $220 million to construct and about $30 million to $35 million a year to operate. The second accelerator is known as the Superconducting Super Collider. DOE has preliminary plans to build this high-energy physics machine at a cost of more than $4 billion.

Accordingly, Senator Johnston asked GAO to compile an inventory of DOE's existing and planned accelerator facilities, identify their costs, and provide information on their benefits. (See app. I and pp. 25, 26, 33 to 35, and 39 to 41.)

DOE'S PHYSICS ACCELERATORS: WHAT ARE THEY AND WHERE ARE THEY LOCATED?

Physics accelerators generally consist of four principal types: electrostatic, linear, cyclotron, and synchrotron. They differ primarily in configuration and how they accelerate a beam of particles toward a given target. Synchrotrons are generally the largest and most powerful. These doughnut-shaped machines are currently capable of accelerating protons to energies of a trillion electron volts[2] and to speeds nearly equal to the speed of light. (See pp. 11 to 19.)

DOE supports 14 physics accelerator facilities located at national laboratories and universities from coast-to-coast. Three of these are for high-energy physics and 11 are for nuclear physics. High-energy physics accelerators are located at the Brookhaven National Laboratory in New York, the Fermi National Accelerator Laboratory in Illinois, and the Stanford Linear Accelerator Center in California. The 11 nuclear physics accelerator facilities are located throughout the country at six national laboratories and four universities. (See pp. 19 to 24.)

Each facility may have several accelerators that are linked together, some of which may operate alone or in conjunction with the others. The original accelerator facility at Fermi, for example, actually consists of four accelerators. The first three serve to produce a beam of protons which are accelerated, in stages, to successively higher energy levels. This beam is ultimately injected into the main accelerator, which is an underground ring having a circumference of 4 miles. Although the typical operating mode is to use the beam from the main accelerator ring, the beam can be extracted from either of the other three accelerators for experimental use.

The primary distinction between accelerators at national laboratories and those that are university-based relates to facility ownership and access. At national laboratories, the facilities are usually federally owned, and accelerator beam time is provided free to all researchers (scientists both within the laboratory and from outside research groups) who have experiments that are judged to be scientifically meritorious. At each laboratory, these judgments are usually made by a committee consisting of members from several laboratories and universities. University-based accelerators were built with federal funds but ownership, in most cases, has been transferred to the universities. Although beam time is also free, the experiments that are carried out are normally those which conform with each university's science curriculum. External researchers, however, may work with university research staff on collaborative experiments. (See pp. 19, 20, and 22 to 24.)

---

[2] An electron volt is a unit of measure that describes the amount of energy acquired by a particle (such as an electron or proton) as it moves across an electric potential of 1 volt.

Aside from the facilities that are currently in place, GAO noted that each facility has ongoing and/or planned projects to upgrade and expand their respective accelerator capabilities. These projects are in addition to DOE's plans for constructing the Superconducting Super Collider and the Continuous Electron Beam Accelerator Facility. Beyond these two entirely new accelerator facilities, GAO also noted that efforts underway at DOE and its laboratories could lead to still other new facilities. Within high-energy physics, one laboratory has begun long-range research which could lead to constructing a device referred to as a large linear electron/positron collider. Within nuclear physics, DOE has recently received proposals for two new facilities: one of these, proposed by Brookhaven National Laboratory, is known as the Relativistic Heavy Ion Collider and the other, proposed by Los Alamos National Laboratory, is a project referred to as LAMPF II, which would be a major addition to that laboratory's existing accelerator. (See pp. 24 to 27.)

HOW MUCH DOES IT COST TO BUILD AND OPERATE DOE'S PHYSICS ACCELERATORS?

DOE's costs of building its existing accelerator facilities amount to more than $1.2 billion (then-year dollars). The bulk of this amount--about $991 million--is for the high-energy physics facilities; Fermilab accounts for more than half. DOE's costs for the 11 accelerator facilities used for nuclear physics amount to about $255 million. Individually, these costs range from about $1.4 million for the facilities located at the University of Washington to nearly $90 million for those at the Los Alamos National Laboratory. DOE estimates that it would cost from $2.5 billion to $3 billion (fiscal year 1985 dollars) to replace all of its current facilities. (See pp. 30, 31, 36 and 37.)

DOE's annual costs for operating these facilities over the past 3 years have averaged more than $365 million, as shown below:

Cost of Operating DOE's Physics Accelerators

Accelerator facilities	1983	1984	1985[a]	3-year average
	(in millions of then-year dollars)			
High-energy physics	$244.4	$257.4	$246.9	$249.6
Nuclear physics	104.8	118.5	125.2	116.2
Total	$349.2	$375.9	$372.1	$365.7

[a] Estimated.

Fermilab (at about $112.1 million for 1985) and Los Alamos National Laboratory (at about $49.1 million for 1985) account for the bulk of costs for operating accelerators in their respective scientific fields. (See pp. 31 to 33 and 37 to 39.)

As part of its review, GAO identified the costs associated with ongoing and planned projects aimed at upgrading or improving the various accelerator facilities. Such projects, as well as entirely new accelerator facilities, are considered necessary by DOE to ensure the United States has facilities for carrying out forefront research. If all of these projects are funded, DOE's investment in high-energy and nuclear physics accelerators could grow significantly. For the two new planned accelerator facilities alone, this growth could total more than $4.3 billion (in fiscal year 1985 dollars) through fiscal year 1994 or from 43 to 72 percent more than DOE's estimated replacement cost for its existing facilities. DOE's annual operating costs for these facilities could similarly grow. DOE estimates that such costs could amount to $230 million or about 60 percent more than current facility operating costs. If increased appropriations are not forthcoming for these increased costs, DOE will be faced with finding other sources to fund these facilities. Three basic options available to DOE, separately or in combination, include:

--Eliminating construction upgrades and improvements in existing facilities to provide funds for operating new facilities.

--Closing one or more of the existing facilities to free operating funds for new facilities.

--Obtaining nonfederal funding to help support the programs. (See pp. 33 to 35 and 39 to 43.)

WHAT IS THE UNITED STATES GETTING FOR ITS INVESTMENT IN ACCELERATOR CONSTRUCTION AND USE?

Aside from the education and training of new scientists in experimental techniques, the benefits derived by the United States from its investment in accelerator construction and use are (1) new knowledge about the size, shape, and other attributes of the atomic nucleus and its component elementary particles, (2) how these particles behave and interact, and (3) the fundamental forces that bind them together. Other benefits are of a more incidental nature. According to DOE and accelerator laboratory officials, accelerator particle beams are now used in other scientific fields and have some medical and industrial applications. (See pp. 43 to 48.)

AGENCY COMMENTS

GAO did not obtain official agency comments on this report. However, GAO did discuss the material presented with DOE officials responsible for the high-energy physics and nuclear physics programs and made changes where appropriate to ensure the report's accuracy.

Contents

Page

DIGEST i

CHAPTER

1 INTRODUCTION 1
- High-energy physics and nuclear physics 1
- Accelerators: Their origin and purpose 3
- The federal government's support of high-energy physics and nuclear physics research 7
- Objectives, scope, and methodology 9

2 DOE'S PHYSICS ACCELERATORS: WHAT ARE THEY AND WHERE ARE THEY LOCATED? 11
- Types of accelerators 11
- DOE high-energy physics and nuclear physics accelerator facilities 19
- Future physics accelerator facilities 24

3 HOW MUCH DOES IT COST TO BUILD AND OPERATE DOE'S PHYSICS ACCELERATORS? 28
- Building and operating accelerator facilities 28
- DOE's funding of high-energy physics 29
- DOE's funding of nuclear physics 35
- Funding of planned physics facilities 41

4 WHAT BENEFITS ARE BEING DERIVED FROM DOE'S HIGH-ENERGY PHYSICS AND NUCLEAR PHYSICS ACCELERATORS? 43
- Physics accomplishments 43
- Industrial applications 44
- Medical and other scientific applications 45
- Societal value 47

APPENDIX

I Letter dated November 25, 1984, from Senator J. Bennett Johnston 49

II Selected capabilities of DOE-supported nuclear physics accelerators 51

III U.S. major accomplishments in high-energy physics since 1945 53

IV U.S. major accomplishments in high-energy physics since 1945, addendum to June 1979 edition 71

CHAPTER		Page
V	Program accomplishments at the nuclear physics accelerator facilities	75
VI	Some major U.S. accomplishments in nuclear physics since 1945	81

ABBREVIATIONS

AGS	Alternating Gradient Synchrotron
CEBAF	Continuous Electron Beam Accelerator Facility
d.c.	direct current
DOE	Department of Energy
eV	electron volt
Fermilab	Fermi National Accelerator Laboratory
FY	fiscal year
GAO	General Accounting Office
GeV	billion electron volts
LAMPF	Los Alamos Meson Physics Facility
MeV	million electron volts
NSF	National Science Foundation
RHIC	Relativistic Heavy Ion Collider
SSC	Superconducting Super Collider
TeV	trillion electron volts

GLOSSARY

Accelerator	A device that increases the energy of motion of charged particles such as electrons and protons.
Alpha particle	A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together (hence, the nucleus of a helium atom is an alpha particle).
Antiparticle	Each particle has a partner, called an antiparticle, which is identical except that all charge-like properties are opposite to those of the particles. When a particle and its antiparticle meet, these properties cancel out in an explosive process called annihilation.
Anti-proton	The antiparticle of a proton.
Atom	A particle of matter indivisible by chemical means. The smallest unit of a chemical element, approximately 1/100,000,000 inch in size, consisting of a nucleus surrounded by electrons.
Atomic mass unit (AMU)	A unit of measure used to compare the mass of atomic particles where AMU 1 is approximately equal to the mass of one proton.
Atomic nucleus	The central core of an atom, made up of neutrons and protons held together by the strong nuclear force.
Beam	A stream of particles or electromagnetic radiation going in a single direction.
Charged particle	An elementary particle of matter that carries a positive or negative charge.
Collider	An accelerator that produces two beams of particles that collide head-on.
Colliding beams	A means of attaining very high energy reactions by accelerating two beams of particles and colliding them head-on.
Continuous electron beam	A continuous stream of electrons produced by an accelerator. In many other accelerators, the beam is delivered to the target in short bursts or pulses rather than continuously.
Cryogenic refrigeration	Refrigeration system used to obtain temperatures near absolute zero--about -273° Centigrade. (See Kelvin, below.)

Cyclotron	An accelerator in which the charged particles are accelerated and spiral outward from the center of the machine.
Detector	A device that can "observe" the presence of a particle or nuclear fragment and measure one or more of its physical properties.
Electromagnetic force	A force associated with the electric and magnetic properties of particles.
Electron	A particle (thought to be an elementary particle) with a unit of negative electrical charge and whose mass is 1/1840 of a proton's mass. Electrons surround an atom's positively charged nucleus and determine the atom's chemical properties. Electrons are members of the lepton family.
Electron-neutrino	One of three distinct types of neutrinos associated with electrons.
Electron volt	A unit of measure that describes the amount of energy acquired by a particle (such as an electron or proton) as it moves across an electric potential of 1 volt. MeV is a million electron volts; GeV is a billion electron volts; and TeV is a trillion electron volts.
Electrostatic accelerator	An accelerator that uses a pulley-driven belt to deposit an electrostatic charge on a metal shell. The charge on the shell provides the force to propel or accelerate charged particles.
Electrostatic charge	The amount of positive or negative electric charge in a body. An uncharged, or neutral, body has equal amounts of positive and negative charge.
Elementary particle	An elementary particle is a particle that cannot be divided. It is a fundamental constituent of matter. Quarks and leptons now appear to be the elementary particles, but the term is often used in referring to any of the subnuclear particles.
Energy Saver	Term used to describe the Fermilab superconducting synchrotron. The use of superconductivity means that little electrical power is necessary to power the magnets and that a higher magnetic field can be created more efficiently.
Fixed target	Where the matter being struck by the accelerator beam particles is at rest.
Fundamental forces	The four basic forces of nature classified as the strong force; the electromagnetic force; the weak force; and the gravitational force.

GeV	(Giga electron volt)--A unit of energy equal to 1 billion (10^9) electron volts.
Gluon	A particle that is hypothesized to mediate or carry the strong nuclear force between quarks.
Gravitational force	A long-range force that affects all particles. It is so weak that it is observable only in massive objects.
Graviton	The hypothetical, perhaps massless particle that is the carrier of gravitational force.
Heavy-ion	All ions with three or more protons. (See Ion.)
Injector	An accelerator whose beam is injected into another accelerator.
Ion	Ions are charged particles which are the result of atoms gaining or losing one or more electrons. Negative ions have more electrons than protons; positive ions have fewer electrons than protons.
Isotope	An isotope is one of two or more atoms having the same number of protons (which makes them the same chemical element) but having a different number of neutrons (which gives them different atomic weights).
Kelvin temperature scale	A scale of temperature based on thermodynamic principles in which zero degrees Kelvin is equivalent to -459°F or -273°C. This temperature is called "absolute zero," where no molecular motion is thought to exist.
Lepton	A member of the family of weakly interacting particles, which includes the electron, muon, tau, and their associated neutrinos and antiparticles.
Linear accelerator, or LINAC	In this type of accelerator, particles travel in a straight line and gain energy by passing once through a series of electromagnetic fields.
Matter	Made up of massive particles: molecules, atoms, and elementary particles. (See elementary particles.)
Meson	A class of strongly interacting particles. Mesons are composed of quark-antiquark combinations.

Molecule	A unit of matter made up of two or more atoms.
Muon	A particle in the lepton family with a mass that is 207 times the mass of the electron and having other properties very similar to those of the electron.
Negative charge	The opposite of positive charge. Electrons carry negative charge. Protons carry positive charge.
Negative ion	Ion that has more electrons than protons.
Neutron	An uncharged particle, within the atom's nucleus, with a mass slightly greater than that of the proton. The neutron is a strongly interacting particle and a constituent of all atomic nuclei except hydrogen.
Neutrino	An electrically neutral, perhaps massless, particle in the lepton family. The only force experienced by neutrinos is the weak force. There are at least three distinct types of neutrino: one associated with the electron, one with the muon, and one with the tau.
Nucleon	A proton or neutron.
Nucleus	The central core of an atom, made up of neutrons and protons held together by the strong force.
Particle	A constituent of matter.
Photon	A quantum or pulse of electromagnetic energy. A particle, perhaps massless, that carries the electromagnetic force.
Pion	One of the family of mesons. It is thought to be the main mediator of the strong force in nuclei. Pions can be electrically charged (positive or negative) or neutral, and have a mass that is about 270 times that of the electron.
Positive ion	Ion that has fewer electrons than protons.
Positron	The antiparticle of an electron.
Proton	A particle with a single positive unit of electrical charge and a mass that is approximately 1,840 times that of the electron. It is the nucleus of the hydrogen atom and a constituent of all atomic nuclei.

Quark	One of a family of particles that may be truly elementary. Each quark is characterized by a number of properties including familiar ones like mass and electrical charge and less familiar ones that are given names like "charm," "strangeness," "top," "bottom," "up," and "down."
Radioactive	The spontaneous transformation of one atomic nucleus into a different nucleus or into different energy states of the same nucleus.
Radio frequency	Refers to the oscillation frequency of electromagnetic field typically associated with radio or television communications.
Radium	A radioactive metallic element that undergoes spontaneous disintegration and transformation.
Strong Force	A short range force, the strongest one known, that affects quarks and all the particles thought to be composed of quarks.
Superconductivity	The ability of some materials to maintain perpetual electric currents without loss, owing to the complete absence of electrical resistance. It is thought to occur only at very low temperatures.
Synchrotron	An accelerator in which the charged particles are constrained to a nearly circular orbit.
Tandem electrostatic accelerator	A d.c. high voltage machine in which negative ions are accelerated toward a positive terminal. Before the ions can reach the terminal they are "stripped" of one or more electrons and become positive ions. These ions are repelled by the positive terminal and then accelerated a second time.
Target	Material subjected to particle bombardment (as in an accelerator) or to irradiation in order to induce a nuclear or subnuclear reaction.
Tau	An elementary particle in the lepton family with a mass that is 3,500 times that of the electron but with similar properties. There are positive and negative tau particles.
TeV	A unit of energy equal to one trillion (10^{12}) electron volts.
Tevatron	A synchrotron accelerator facility located at Fermilab using superconducting accelerator magnets to produce 1-TeV beams.

W and Z bosons	The massive particles that are thought to be the carriers of the weak force.
Weak force	A short-range force that affects all quarks and leptons. It is responsible for the radioactive decay of many particles and nuclei.
X-rays	Photons of electromagnetic radiation produced when high energy atoms decay to states of lower energy.

CHAPTER 1

INTRODUCTION

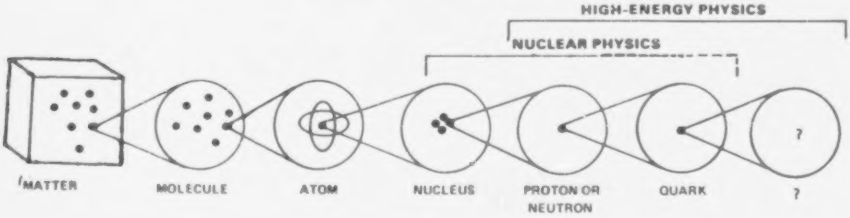
Physics is a science that deals with matter and energy and how they interact in such diverse areas as mechanics, acoustics, astronomy, optics, heat, electricity, magnetism, radiation, atoms, and the atom's nucleus. The physics discussed in this report generally concerns the "atom's nucleus" portion of physics, and the report examines the use of machines called accelerators (sometimes referred to as "atom smashers") to conduct physics experiments. More specifically, the report describes the Department of Energy's (DOE's) programs to fund the construction, operation, and improvement of high-energy physics and nuclear physics accelerator facilities and provides information on the costs and benefits of these efforts.

HIGH-ENERGY PHYSICS AND NUCLEAR PHYSICS

High-energy physics (sometimes called elementary particle physics) and nuclear physics have a common heritage: both are basic sciences (that is, their primary goal is to increase knowledge and understanding of our natural environment); both speak the abstract language developed and nurtured by the mathematics theorist and the research experimentalist; and both use large, complex machines at national laboratories and universities to explore, among other things, the structure and fundamental characteristics of matter and energy.

Matter, as shown in the diagram below, is thought to have several layers of component parts. The quest for high-energy physics involves the search, discovery, and understanding of the most fundamental components and structure of matter. The high-energy physicist is concerned with the interactions, structure, and other characteristics of these fundamental components and the most basic forces of nature (see p. 3) that affect them. Nuclear physics, on the other hand, is primarily concerned with

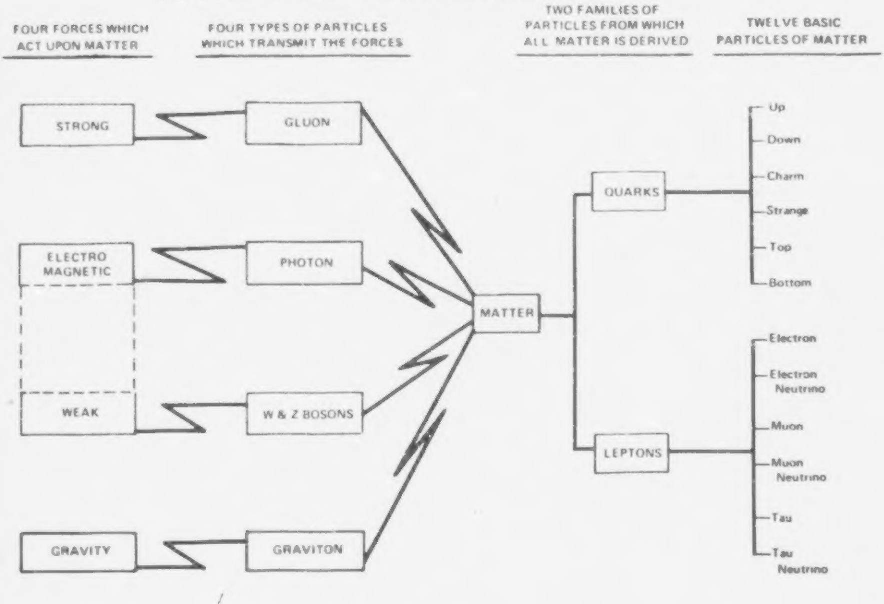
COMPONENTS OF MATTER



the interactions, structure, and other fundamental characteristics of the atom's nucleus. This distinction between high-energy physics and nuclear physics could not have been made 60 years ago, when the proton and electron were recognized as the "indivisible" fundamental components of matter. However, in 1932, the neutron was identified as the atom's second nuclear component and since then--and especially within the last 30 years--numerous subnuclear particles have been discovered. (The dashed line in the diagram for nuclear physics is used to indicate a growing interest by nuclear physicists in understanding the nucleus through the study of the characteristics and behavior of quarks.)

As more and more particles were discovered, it was felt that there were too many for them all to be considered the fundamental components of matter. So, experiments were devised to probe deeper to see if these particles were themselves divisible and if they were comprised of a few common elementary bits of matter. The "standard model" depicted below reflects the physics community's current thinking about the universe of fundamental particles and forces of nature: 12 basic particles of matter (split into 2 "families"), 4 forces which affect matter, and 4 types of particles to transmit those forces among particles of matter.

THE PHYSICS STANDARD MODEL OF NATURE'S FUNDAMENTAL PARTICLES AND FORCES


FOUR FORCES WHICH ACT UPON MATTER
FOUR TYPES OF PARTICLES WHICH TRANSMIT THE FORCES
TWO FAMILIES OF PARTICLES FROM WHICH ALL MATTER IS DERIVED
TWELVE BASIC PARTICLES OF MATTER
STRONG
GLUON
ELECTRO MAGNETIC
PHOTON
WEAK
W & Z BOSONS
GRAVITY
GRAVITON
MATTER
QUARKS
LEPTONS
Up
Down
Charm
Strange
Top
Bottom
Electron
Electron Neutrino
Muon
Muon Neutrino
Tau
Tau Neutrino

The standard model is dynamic and is not meant to necessarily represent the "final solution." The dashed lines that connect the electromagnetic and the weak forces in the above diagram highlight the fact that these two forces have recently been shown to be two manifestations of the same phenomenon: the electroweak force. The electromagnetic force itself was recognized in the 19th century as a single force that linked the properties of electricity and magnetism. Scientists see the next possible simplification of the model to be a linking of the strong and electroweak forces. The final step would then link the strong-electroweak force to gravity.

Matter in the standard model

All matter in our everyday world is thought to be composed of only two of the six types of quarks (up and down) shown in the diagram on page 2, and two of the six types of leptons (electron and electron neutrino). The protons and neutrons in all nuclei are made up of these two quarks; electrons orbit nuclei to make atoms; and electron neutrinos are ejected from the atom's nucleus during the natural radiation process of some radioactive materials. Three of the remaining four quarks and the remaining four leptons shown in the diagram on page 2 can be created under experimental conditions but are elusive, unstable, and/or short-lived. There is a strong theoretical basis for the existence of the last quark (the top quark) and it may have been observed experimentally but this has yet to be confirmed.

The four forces in the standard model

The strong force binds the protons and neutrons within the nucleus and the quarks within the protons and neutrons. While it is the strongest of the forces, it is effective only over a short range (approximately the width of one proton). The electromagnetic force holds the electrons in their orbits around the nucleus and binds atom to atom and molecule to molecule; it is weaker than the strong force but is effective over a greater distance. The weak force governs the radioactive decay of many particles and nuclei and is weaker than the electromagnetic and strong forces. Gravity is the weakest force but has the greatest effective range and seems to affect all matter.

ACCELERATORS: THEIR ORIGIN AND PURPOSE

Accelerators are complex machines that enable the physicist to "see" inside the atom and its nucleus and study the substructure of nuclear particles having dimensions billions of times smaller than the smallest object that can be seen with an optical microscope. Generally, as the particles of matter to be studied become smaller, or more elementary, their component parts are bound together more tightly thereby requiring larger, more powerful and complex accelerators and other supplementary equipment such as particle detectors (see p. 6) to study them. The following excerpt from a DOE publication[1] presents an analogy that provides insight into the use of the accelerator, the logic that led to its development, and the scientists' rationale for needing more powerful machines.

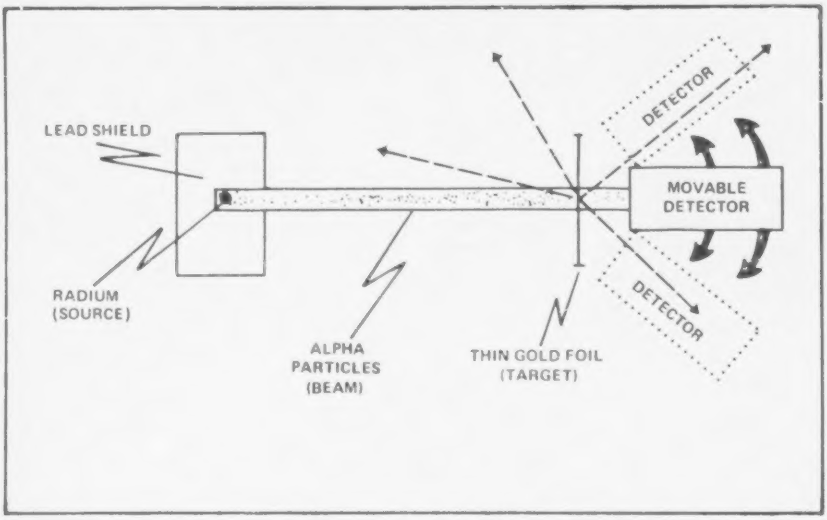
> "In order to understand the need for larger and larger accelerators, it may be instructive to consider an outrageous analogy. Suppose that we were obliged to study the structure of a peach simply by shooting small projectiles, such as BB's at it. [The peach is shrouded in a fog and cannot be seen by the marksman.]
>
> "A beam of very slow BB's would simply bounce off the peach. By measuring the pattern of scattered BB's, we could learn the size of the peach and that it is round. Faster BB's would lodge within the peach, perhaps causing the production of a secondary product: we could learn that the peach is soft and juicy. With a more powerful BB gun, most of the projectiles would pass straight through the peach. Some, however, would change their direction to emerge from the peach at large angles. How would we understand this? We might conjecture the existence of a small hard 'pit' within the peach. A detailed study of the large-angle scattering of high-energy BB-peach collisions would reveal the size, shape, and weight of the pit. Of course, the pit itself has structure too. A still more powerful BB gun is needed to shatter the pit and reveal the kernel within . . . .
>
> "Let us emerge from the analogy to the real world of atoms and atomic constituents. To study the structure of matter, the projectiles should be chosen to be as simple as possible: hydrogen nuclei (protons), electrons, particles of light (photons), etc. Furthermore, there is a fundamental law of physics that says: the smaller an entity, the higher are the energies involved which hold its component parts together. Therefore, we need higher energies to find out the structure of smaller entities."

The accelerator is the physicist's "BB gun" for exploring the atom and its components. Its roots are found in a series of experiments performed by British physicist Ernest Rutherford, between 1908 and 1913. In his experiments, Rutherford used the alpha particles (natural radiation) from radium as his "BBs" to bombard gold atoms (his "peach"). He then rotated a detection device around the gold foil target to determine the effect of this bombardment. Through these experiments, Rutherford discovered the basic structure of the nuclear atom--an atom where relatively light-weight, negatively charged electrons orbit a very small and dense nucleus that is positively charged.

---

[1] High Energy Physics, the Ultimate Structure of Matter and Energy (DOE/ER-0027, Apr. 1979).

THE RUTHERFORD EXPERIMENTS



Physicists discovered rather quickly that if they were going to be successful in studying the atom in greater detail, they would need "BB guns" that were more powerful and more accurate and over which they could exercise more control. This need began to be met with the development of the first accelerators in the early 1930's. These original accelerators, and those developed since have followed the methodology used by Rutherford:

--There is a source of charged particles.

--The charged particles are set in motion by various means and directed in a beam to a target.

--The beam strikes a target and the results of the collisions are recorded by a detector.

Beam/target collision

Once the beam of particles is accelerated to the desired energy level, the next phase of the high-energy physics or nuclear physics experiment is common to all accelerators--the beam/target collision. Increased energy levels for beam/target collisions can be obtained by using two or more accelerators in combination--that is, particles can be accelerated in one machine, directed to and injected into another, and accelerated a second time before being directed to a target. One accelerator at Oak Ridge, Tennessee, for example, is used to inject another accelerator for nuclear physics experiments. At a high-energy physics facility near Chicago five accelerators are used in sequence. (See pages 19 to 24 for a description of all DOE-supported high-energy physics and nuclear physics facilities.)

Besides building more powerful machines or connecting them in series, a third way to obtain more powerful particle collisions is to collide two beams together, instead of colliding a single beam into a fixed target. For example, if a beam of protons with an energy level of 16 billion electron volts[2] (GeV) collides with a fixed target, the effective energy of the collision is reduced to about 4-GeV (approximately the square-root of the beam's energy). However, if an 8-GeV proton beam collides head-on with another 8-GeV proton beam, the energies are added for a combined effective collision of 16 GeV.

Detectors

Devices built to observe the particle collisions and record the results are called detectors. A variety of detectors have been developed to detect, identify, or measure both the beam particles and the secondary particles that result from the collisions. The detectors can be relatively small and uncomplicated devices or large, complex devices which use extremely fast, large-memory computers to record millions of bits of information associated with a single particle collision. According to a DOE official, much of physics research progress and the successes of accelerator programs can be attributed to the development of detector technology.

---

[2] An electron volt (eV) is a unit of measure that describes the amount of energy acquired by a particle (such as an electron or proton) as it moves across an electric potential of 1 volt. MeV is a million electron volts; GeV is a billion electron volts; and TeV is a trillion electron volts.

THE FEDERAL GOVERNMENT'S SUPPORT OF HIGH-ENERGY PHYSICS AND NUCLEAR PHYSICS RESEARCH

DOE and the National Science Foundation (NSF) are the two federal agencies primarily responsible for funding high-energy physics and nuclear physics research. DOE provides about 90 percent and 80 percent, respectively, of the federal dollars for high-energy physics and nuclear physics. The NSF provides the rest.

DOE'S high-energy physics and nuclear physics programs

DOE has no specific mandate to support high-energy physics or nuclear physics research programs other than that which is contained in DOE's annual appropriations acts. However, DOE's policy is to support scientific and technical research that advances the frontiers of scientific and engineering knowledge. While DOE's fiscal year 1986 budget document states that high-energy physics and nuclear physics programs have no direct application to energy, DOE feels this research will provide the underlying basis for future technological innovation. Also, DOE feels it is specifically responsible for supporting basic research "where the incentive for and the availability of private investment are severely limited or nonexistent."

The DOE budget for its high-energy physics program in fiscal year 1985 is $545.6 million. Specific program objectives include:

--the search for and discovery of new physical phenomena using high-energy subnuclear particle interactions,

--the pursuit of advanced concepts and technology development, and

--the maintenance of the U.S. program in a world leadership position.

A DOE High Energy Physics Advisory Panel was established in 1967 to review the program and provide advice on overall program balance, scientific priorities and special problems. A subpanel for long range planning was formed in 1981 to review the status and prospects of the DOE and NSF high-energy physics programs. The subpanel issued its report[3] in 1982. Advisory panel members are appointed by the Secretary of Energy and are affiliated with universities that have DOE-sponsored high-energy physics programs and/or with high-energy physics programs at DOE's national laboratories. These laboratories are government-owned facilities that are operated for DOE by contractors. While DOE and NSF employees participate in the advisory panel's activities, they do not officially represent those agencies.

---

[3] Report of the Subpanel on Long Range Planning for the U.S. High Energy Physics Program of the High Energy Physics Advisory Panel (DOE/ER-0128, Jan. 1982).

The DOE budget for its nuclear physics program in fiscal year 1985 was $182.9 million. The program has several major objectives including the following:

--Describing quantitatively the behavior and structure of complex nuclei in terms of fundamental interactions.

--Using nuclei as a laboratory for the study of fundamental forces of nature.

--Advancing research capability by developing new facilities and improving particle beams and ancillary equipment at existing facilities.

--Maintaining a position of leadership in nuclear research for the United States.

DOE and NSF established a joint committee in 1977 called the Nuclear Science Advisory Committee to provide both agencies with advice on a continuing basis regarding the scientific priorities within the field of nuclear physics research. To this end, the advisory committee published its first long-range plan for nuclear science in 1979 and updated that document with another plan in 1983.[4] The advisory committee has members from national laboratories and universities which have DOE or NSF sponsored programs. These members are selected by the Secretary of Energy and the Director of NSF. As with the High Energy Physics Advisory Panel, DOE and NSF employees affiliated with the advisory committee do not participate as official representatives of their agencies.

NSF's high-energy physics and nuclear physics programs

NSF is the principal federal agency for the support of basic research across all fields of science and science education. It supports one high-energy physics accelerator facility (a national laboratory at Cornell University) and 12 nuclear physics accelerator facilities (two national laboratories at Indiana and Michigan State Universities and 10 other university-based facilities). In fiscal year 1985, NSF provided--through grants and contracts--about $47.3 million for high-energy physics and about $44.2 million for nuclear physics activities and facilities. These amounts include money to support accelerator facilities operations as well as accelerator and detector research and development, theoretical physics studies, and efforts at various laboratories by outside user groups. As mentioned above, NSF participates in activities of the High Energy Physics Advisory Panel and Nuclear Science Advisory Committee.

---

[4] A Long Range Plan for Nuclear Science (DOE/NSF Nuclear Science Advisory Committee, Dec. 1983).

OBJECTIVES, SCOPE, AND METHODOLOGY

In his November 25, 1984, letter (see appendix I) to us, Senator J. Bennett Johnston, Ranking Minority Member, Subcommittee on Energy and Water Development, Senate Committee on Appropriations, stated that DOE's plans to build two new accelerators have increased the subcommittee's concerns about the need for larger, more costly high-energy physics and nuclear physics facilities. Senator Johnston requested that we develop information related to DOE's high-energy physics and nuclear physics programs and facilities. Specifically, he requested that we

- --compile an inventory of accelerators that have been built or are planned for construction in the United States;
- --identify the construction, operation, and maintenance costs associated with those accelerators; and
- --identify the benefits being derived from the construction and operation of the accelerators.

To obtain general background information on accelerator physics, how accelerators function, and the federal government's role in high-energy physics and nuclear physics, we conducted a literature search, reviewed pertinent articles and studies, and held discussions with officials representing DOE, NSF, the National Academy of Sciences, the Office of Science and Technology Policy, the Office of Management and Budget, the High Energy Physics Advisory Panel, and the Nuclear Science Advisory Committee.

To help compile an inventory of the existing accelerators, we visited all accelerator facilities funded by DOE's high-energy physics and nuclear physics programs. At each location we ascertained--through discussions with accelerator management personnel and review of pertinent documents--the type(s) and power range(s) of the accelerator(s), the type of beam(s) produced, the costs of the accelerators and related equipment, the nature of experiments normally conducted, the number of experiments conducted, facility historical data, and the major accomplishments that could be attributed to research conducted at the accelerator facility.

To develop information on accelerators that are planned for future operation or construction, we reviewed current physics and accelerator periodicals, held discussions with DOE and accelerator facility officials, and reviewed budgetary documents. We also obtained information on facility improvements planned for existing accelerators by reviewing related proposals submitted to DOE and by holding discussions with accelerator facility and DOE officials.

Operating cost data were obtained from DOE's Financial Information System and were compared with data obtained at the accelerator facilities visited. Acquisition cost data were obtained from accelerator facility officials and were compared with pertinent cost records. Conversion of cost data to current-year dollars was accomplished by using the annual inflation rate reported in the Economic Report of the President, February 1985. (This report is submitted to the Congress with the Annual Report of the Council of Economic Advisors). Cost information presented in the tables in chapter 3 was compiled by GAO based on data supplied by DOE and accelerator facility officials. Information on the cost of future accelerator construction and improvements was obtained from review of proposals and information submitted to DOE from the accelerator facilities and from discussions with DOE and accelerator facility officials.

To obtain information on the benefits derived from constructing and operating high-energy physics or nuclear physics accelerators, we reviewed pertinent literature and documents and discussed the subject with accelerator facility officials. We then compiled a narrative discussion summarizing the benefits identified and obtained from DOE a more technically-oriented listing of derived benefits. In addition, we asked DOE program officials to compile a listing of program accomplishments. The resulting documents are included as appendixes III through VI to this report.

While Senator Johnston has stated his preference for obtaining official agency comments on draft reports prepared by GAO, as agreed with his office, we did not obtain such comments on this report to ensure its issuance in time for use during the current budget cycle. Nevertheless, we did discuss the report with DOE program officials, and changes were made where necessary to ensure the report's accuracy. Except for not obtaining official DOE comments, our review was performed in accordance with generally accepted government auditing standards between November 1984 and March 1985.

CHAPTER 2

DOE'S PHYSICS ACCELERATORS: WHAT ARE THEY AND WHERE ARE THEY LOCATED?

Accelerators and their ancillary equipment and the facilities to house them can cost hundreds of millions of dollars to construct and operate. They can take the shape of a grain silo, a 2-mile long tube, or a circle 4 miles in circumference. A circular accelerator currently being considered for construction in the United States could have a circumference of between 60 and 120 miles.

DOE provides funds to build, improve, and operate high-energy physics and nuclear physics accelerator facilities at national laboratories and universities across the nation. Different types of accelerators at these facilities generate a wide variety of particle beams for research. In addition to the current facilities, DOE is developing plans for one new high-energy accelerator facility and one new nuclear physics facility and is evaluating a proposal for another nuclear physics facility. Scientists in the high-energy physics and nuclear physics communities are also developing other proposals for new accelerator facilities designed to continue scientific research in the next decade.

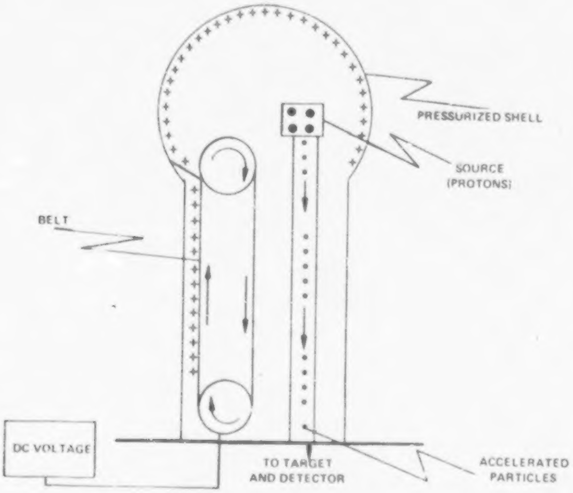
TYPES OF ACCELERATORS

There are four basic types of accelerators and they all use the same four principal components outlined in chapter 1: a source of particles to be accelerated, a beam of accelerated particles directed toward a target, and a detector that records the results of the beam-target collision. These four types of accelerators also share a common principle of operation: they use basic laws of electromagnetism to accelerate particles (one principle is that objects with opposite electric charge attract each other, and those with similar electric charges repel each other). The main distinction between the four accelerators is in configuration and the manner in which the beam is speeded up and directed to the target. The four types of accelerators and a simplistic explanation of how each accelerates a beam of particles follows.

Electrostatic accelerators

Electrostatic charge is responsible for the shock one sometimes gets when touching something metallic after walking across a carpet or for the crackling-popping noises one may hear when pulling fuzzy sweaters or socks out of a clothes dryer. Electrostatic accelerators are relatively simple machines that create and harness electrostatic charge.

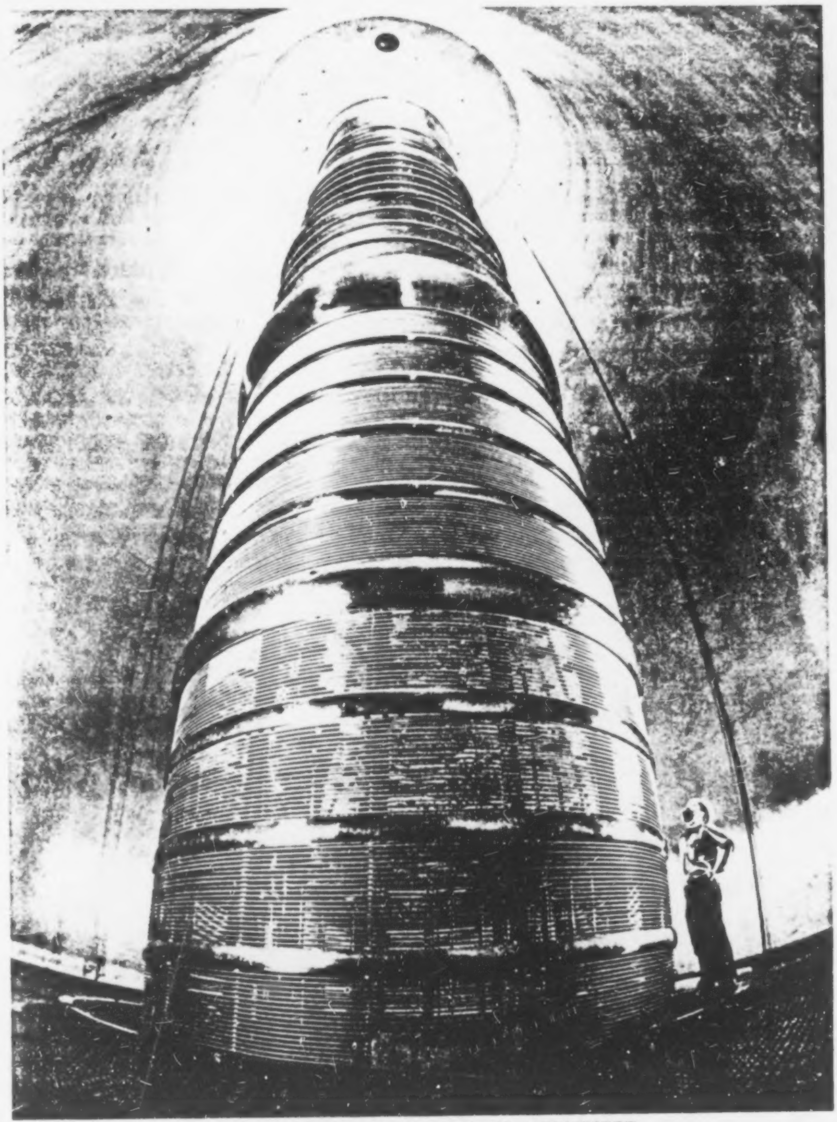
The principles of how an electrostatic accelerator works are illustrated in the diagram below. A direct current (d.c.) voltage provides a positive charge to a belt, the belt rotates around two pulleys, and the belt deposits its positive charge to the top of the dome. When the dome becomes fully charged, the positively charged particles from the source are accelerated down the acceleration tube--repelled by the positively charged dome and attracted toward the end of the tube that is negatively grounded.



A modification to this process is the tandem electrostatic accelerator, where negative ions[1] are introduced near the negative ground and accelerated toward the positively charged dome. Before the negative ions reach the dome, they collide with a target that strips them of their extra electrons plus one or more of their original electrons so that they are now positively charged ions (atoms with more protons than electrons).

---

[1] Ions are charged particles which are the result of atoms gaining or losing one or more electrons. Negative ions have more electrons than protons; positive ions have fewer electrons than protons.



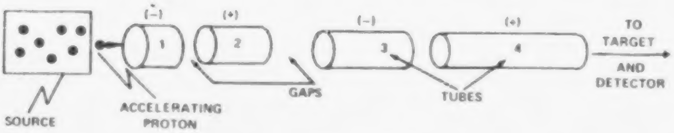
THE ELECTROSTATIC ACCELERATOR AT OAK RIDGE, TENNESSEE.

The positive ions are then accelerated for the second time--away from the positively charged dome and toward the negative ground. The tandem version of the electrostatic accelerator can double the accelerator energies of the single version. The picture on the preceeding page shows the tandem electrostatic accelerator at the Holifield Heavy Ion Research Facility in Oak Ridge, Tennessee. (See pp. 19 to 24 for a description of all high-energy and nuclear physics facilities supported by DOE.)

Linear accelerators

In a linear accelerator, charged particles (electrons, protons, or heavy ions[2]) travel in a straight line and gain energy by passing through a series of electrically charged tubes. The tubes alternate at regular cycles with either a positive or a negative charge. In the diagram below, protons, which have a positive charge, are being accelerated from the source to the target (from left to right).

PHASE I: PROTON IS ACCELERATED FIRST TIME



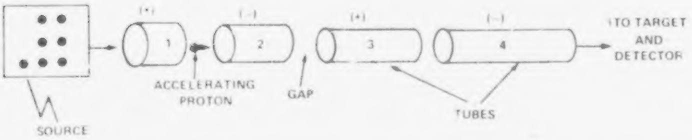
In phase I (depicted above), protons are produced at the source and are attracted (accelerated) toward tube number 1 because the tube's surface is negatively charged. (At this point, all odd numbered tubes are negatively charged and all even numbered are positively charged.) Once inside the tube, the protons are unaffected by the charge on the tube's surface and they continue their movement toward the number 2 tube and the target.

As shown in the diagram below, when the protons exit tube number 1, the electrical charge on all tubes has been reversed (all even numbered tubes are now negatively charged). The protons are now accelerated a second time because they are repelled by the positive charge behind them in tube number 1 and they are attracted to the negative charge of tube number 2 in front of them. This process is repeated for the length of the electric field and the protons are speeded up at each gap.

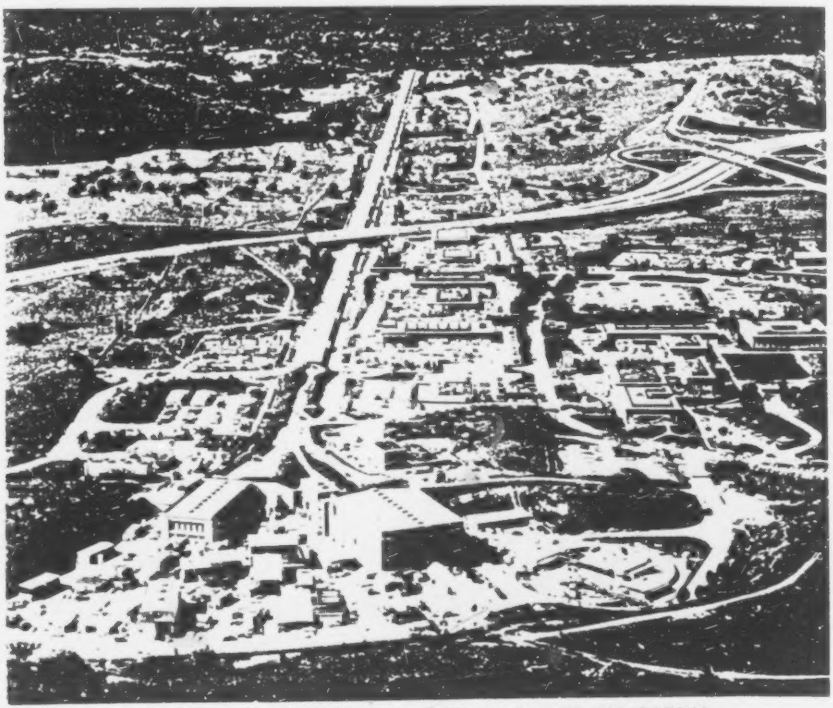
---

[2] Helium and hydrogen, which consist of one and two protons, respectively, are considered "light" ions; all ions with three protons (lithium) or more are considered "heavy" ions.

PHASE II: PROTON IS ACCELERATED SECOND TIME


(+)
(−)
(+)
(−)
1
2
3
4
TO TARGET AND DETECTOR
ACCELERATING PROTON
GAP
TUBES
SOURCE

This method of proton acceleration requires that the electrically charged tubes get progressively longer and longer. The reason for this is that the tubes switch their positive and negative charges at a constant rate but the protons are going faster and faster, and therefore, take less time to go the same



THE STANFORD LINEAR ACCELERATOR CENTER, PALO ALTO CALIFORNIA.

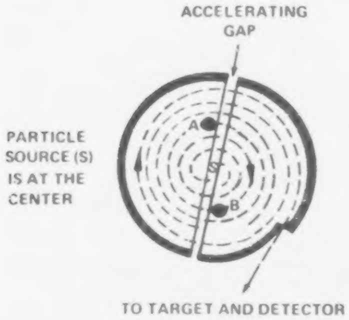
distance. If the tubes' size remained the same, the protons would progressively take less and less time to traverse the length of each tube and would soon be exiting a tube before the electrical charge is switched. If the protons enter a gap where the positively charged tube is in front of them instead of behind them they will be decelerated. Since electrons are so much lighter than protons, they achieve maximum velocity (nearly the speed of light) very quickly so most of the tubes in an electron accelerator do not progressively increase in length.

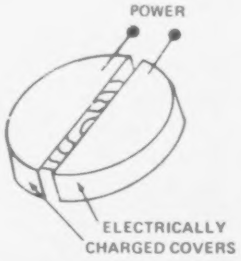
The picture on page 15 shows the Stanford Linear Accelerator Center. The accelerator crosses under a major highway and is approximately 2 miles long. The large buildings at the bottom of the picture house some of the experimental areas.

Cyclotrons

The cyclotron uses the same principle as the linear accelerator--the particles get accelerated as they cross a gap between two areas which have an opposite electric charge. However, instead of a long straight tube, the cyclotron is circular and the accelerating gaps form a straight line in the center between two electrically charged "D"-shaped covers as shown in the sketch below. (The sketch on the left is a top view). The particles are injected into the center of the machine and magnets then cause the particles to move in a circular fashion, spiraling outward as they pick up speed.

The "D"-shaped covers--like the tubes in the linear accelerator--switch back and forth between positive and negative electrical charges at regular intervals so that when a particle approaches the gap, the D-cover on the far side will have an opposite charge. For example, when a proton (which has a positive electrical charge) is in position "A" (under the left D-cover),





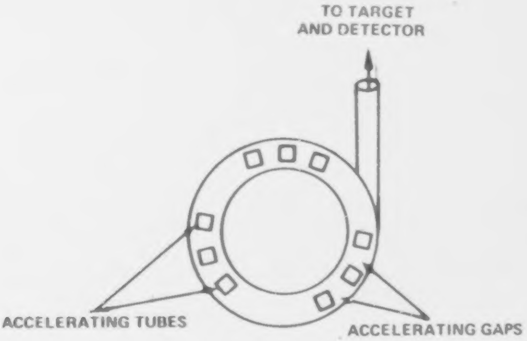
the right D-cover will be negative to pull the proton across the gap as the left D-cover (which is positive) repels or pushes the proton across the gap. By the time the proton gets to point "B," the D-covers have switched their electrical charges again and are ready to repeat the acceleration cycle.

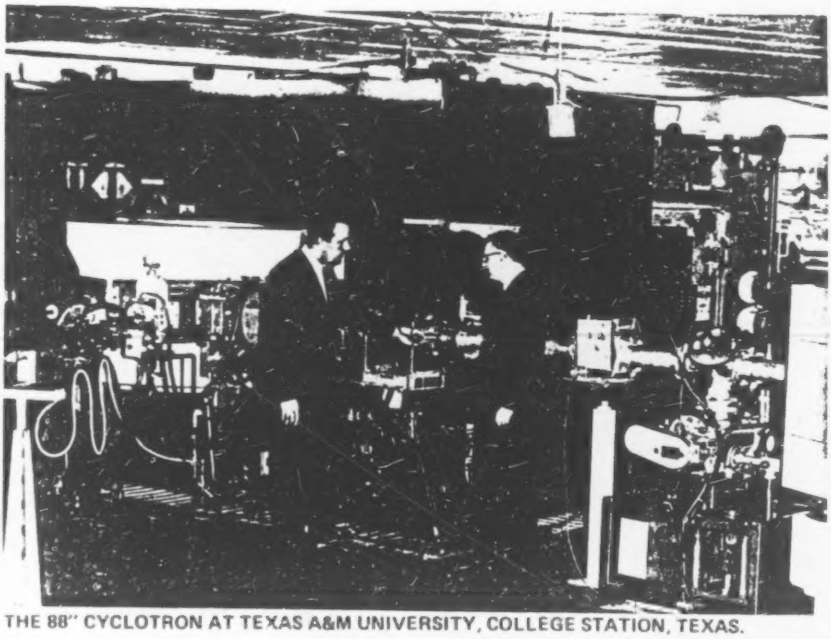
Like the tubes for the linear accelerator, it is essential that the cyclotron's D-covers have the correct electrical charge when the accelerated particle reaches the gap. Since the D-covers alternate electrical charge at a constant rate and the accelerated particles move faster every time they are accelerated across the gap, an adjustment must be incorporated to ensure that the particles do not reach succeeding gaps too soon. The time required for the particles to make a single orbit must remain the same throughout the acceleration process. This is achieved through the spiraling path the particles are forced to take--with each succeeding revolution, a particle is moving at faster speeds, but because of its spiral path, the particle also has farther to travel before it reaches the gap.

The picture on the following page shows the Texas A&M University cyclotron. The long white object to the left of the two men is a side view of the cyclotron. The dark areas above and below the cyclotron are the magnets that impart the spiraling motion to the accelerated particles.

Synchrotrons

The largest and most powerful accelerators today are synchrotrons. Just like the linear accelerator, the synchrotron has a series of tubes and accelerating gaps, but the similarity ends there. As shown in the sketch below, a synchrotron is doughnut-shaped and, unlike the linear accelerator, the synchrotron's tubes do not have to progressively increase in length because the frequency of change in each tube's electrical charge is synchronized to match the accelerated particle's speed. This means that as the

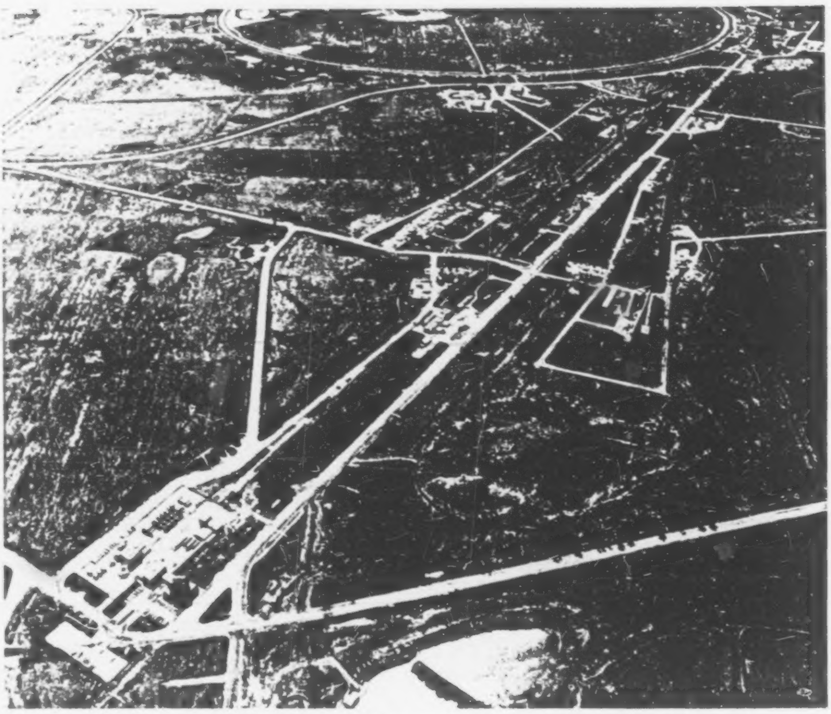




THE 88" CYCLOTRON AT TEXAS A&M UNIVERSITY, COLLEGE STATION, TEXAS.

speed of the particle increases, the electrical charge of the tubes remains correctly phased--the tube immediately in front of the accelerated particle will always have an opposite charge. A magnetic field, used to bend the beam of particles and keep it in the "doughnut" (ring), also varies in strength with the momentum of the particles. When the correct energy levels are achieved, the accelerated beam of particles is diverted (by magnets) out of the ring and toward the target area.

An aerial view of the Fermilab synchrotron facility is pictured on the next page. The accelerator is about 4 miles in circumference, and it can accelerate protons around the ring at a rate of nearly 50,000 times a second (nearly the speed of light) with energy levels up to 800 GeV.



FERMI NATIONAL ACCELERATOR LABORATORY, BATAVIA ILLINOIS.

DOE HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS ACCELERATOR FACILITIES

DOE supports high-energy physics and nuclear physics experiments at several national laboratories and university-based laboratories. High-energy physics and nuclear physics accelerators located at national laboratories are usually government-owned and contractor-operated. They provide free "beam time" to all scientists conducting experiments at the facility, and experiments are approved at each location on the basis of their scientific merit by a committee whose members represent several laboratories and universities. Scientists in outside research groups can also conduct experiments at the national facilities. However, they must plan experiments and fabricate detectors and other instruments at their home institutions, execute and partially analyze experiments at the national facility, complete analyses at their home institutions, and ultimately, publish their research results.

University-based facilities, on the other hand, may be available for collaborative efforts with scientists from other laboratories and universities but are usually dedicated to a research program that is established as part of the university science curriculum. The accelerators at university-based laboratories are usually owned by the university and beam-time is provided without charge for scientifically meritorious research.

High-energy physics accelerator facilities

The three DOE high-energy physics accelerator facilities are located at Brookhaven National Laboratory, Fermi National Accelerator Laboratory, and Stanford Linear Accelerator Center. All three laboratories have the common goal of seeking the fundamental components and structure of energy and matter. They differ in the type of accelerator beams produced and the energy levels of the machines.

Brookhaven National Laboratory

Brookhaven National Laboratory in Upton, New York, is government-owned and operated by Associated Universities Incorporated, a nonprofit consortium of nine universities. Brookhaven uses a 750,000 eV electrostatic accelerator and a 200 MeV linear accelerator to inject the main accelerator--a 33-GeV synchrotron. The three machines (known collectively as the Alternating Gradient Synchrotron, or AGS) accelerate protons, and during normal operations, up to 7 experiments can be conducted concurrently. Full beam energy was obtained from Brookhaven's original main accelerator in 1960. Since 1965, the accelerator facility has been upgraded several times, including the addition of a new magnet power supply and a new experimental hall.

Work began in 1984 to connect the AGS with an existing nuclear physics electrostatic accelerator. This will allow heavy-ions to be injected into the AGS and accelerated to higher energy for nuclear physics experiments. According to DOE, this upgrade would be beneficial if another accelerator, a heavy-ion collider, were to be built at Brookhaven since the Brookhaven accelerators could then be used collectively as an injector for the new accelerator. (See page 26.). Fiscal year 1986 funds were requested by Brookhaven for a second project--a new synchrotron booster--but funds for this project were not included in the President's fiscal year 1986 budget request.

Fermi National Accelerator Laboratory

Fermi National Accelerator Laboratory (Fermilab), located near Chicago, Illinois, achieved full beam energy on its original accelerator in 1971. Fermilab is a government-owned facility that is operated for DOE by a consortium of 54 universities--University Research Associates, Incorporated. The Fermilab accelerator facility consists of a series of five accelerators that successively boost proton beams to higher energies. The beam originates in a 750,000 eV electrostatic accelerator and is then injected into a 500-foot-long linear accelerator. The beam emerges from the linear accelerator with energies of about 200 MeV. The third accelerator is a booster synchrotron--about 500 feet in diameter--that boosts the protons to about 8 GeV and injects the beam into the main synchrotron ring that is about 4 miles in circumference. Protons can be accelerated by this fourth accelerator to about 500 GeV but is limited to about 150 GeV when the fourth accelerator is used as an injector to the fifth accelerator.

In December 1983 Fermilab began operating with a fifth accelerator, called the "Energy Saver," which uses a ring of superconducting magnets[3] to boost the energy of the particles being examined to about 800 GeV. This accelerator will be capable of accelerating protons to about 1 TeV when an upgrade of the facility (called Tevatron I) is completed.

The Tevatron I project will also enable the facility to operate in a second mode--colliding beams. Fermilab is modifying its facilities so that a proton beam circling within the superconducting ring of magnets, can be collided with an antiproton[4] beam that is circling in the opposite direction within the same magnet ring, at energies up to 1 TeV for each beam. Project completion is scheduled for 1986.

Stanford Linear Accelerator Center

Stanford Linear Accelerator Center, located near Palo Alto, California, is operated for DOE by Stanford University. The Center's original 2-mile-long linear accelerator achieved full beam energy of 21-Gev in 1966. With subsequent upgrades and improvements, the accelerator now produces electron and positron[5] beams at energies up to 32-Gev and injects those beams into two circular electron-positron colliding-beam facilities--one almost 270 feet in diameter, producing collision energies of 8 GeV (called SPEAR), and the other almost 2,700 feet in diameter, producing collision energies of 30 GeV (called PEP). The linear accelerator can be operated independently or as an injector to the colliding-beam facilities. Up to ten experiments can be run concurrently at the Stanford Center.

---

[3] Superconductivity refers to the ability of some materials to maintain perpetual electric currents without loss, owing to the complete absence of electrical resistance. It occurs at very low temperatures.

[4] An antiproton is the antiparticle of a proton. When a particle and its antiparticle meet, the result is annihilation of the two particles.

[5] A positron is the antiparticle of an electron.

A linear collider accelerator is currently under construction at the Stanford Center. The primary goals of this new accelerator are to test the feasibility of the linear-collider concept and to explore electron-positron colliding-beam physics at energy levels of 100 GeV. Construction began in October 1983 and includes upgrading the energy level of the existing linear accelerator from 32 to 50 GeV so it can serve as an injector to the linear collider. Project completion is scheduled for late 1986.

Nuclear physics accelerator facilities

DOE provides support for 11 accelerator facilities; 7 are at national laboratories and 4 are at university-based laboratories. The accelerators at the national laboratories are owned by the government. One of the accelerators at the university-based facilities (Yale) is also owned by the government; the others are owned by the universities.

At DOE's nuclear physics accelerator facilities, scientists have access to each of the four types of accelerators described on pages 11 through 19: electrostatic, linear, cyclotron, and synchrotron (and at some facilities, combinations of these accelerators). While the types of beams are duplicated at several of these facilities--many provide light-to-heavy ion beams--the energy range and program emphasis often varies. Listed in the table on the following page is each of DOE's nuclear physics facilities, their location, and the type of accelerator used. All of the accelerators in the table accelerate protons except the Bates machine which accelerates electrons. Additionally, while the Los Alamos machine accelerates protons as its primary beam, this beam is merely a catalyst used to produce muon, neutrino, and pion beams.[6] These three secondary accelerator beams are the primary experimentation beams. A table is provided in appendix II to show selected capabilities of the DOE-supported nuclear physics accelerators. (See p. 51.)

DOE-Supported Nuclear Physics Accelerators

Facility	Location	Accelerator name	Accelerator type
A. W. Wright Nuclear Structure Laboratory	Yale University New Haven, Connecticut	Tandem Van de Graaff Accelerator	Electrostatic
Argonne National Laboratory	Argonne, Illinois	Atlas	Electrostatic injecting a linear
Brookhaven National Laboratory	Upton, New York	Tandem Heavy Ion Facility	Two electrostatics
Cyclotron Institute	Texas A&M University College Station, Texas	Texas A&M Cyclotron	Cyclotron
Lawrence Berkeley Laboratory	Berkeley, California	88-Inch Cyclotron	Cyclotron
Lawrence Berkeley Laboratory	Berkeley, California	Superhilac/Bevalac	Linear injecting a synchrotron
Los Alamos National Laboratory	Los Alamos, New Mexico	Clinton P. Anderson National Meson Physics Facility (LAMPF)	Linear
Massachusetts Institute of Technology	Massachusetts Institute of Technology Middleton, Massachusetts	Bates Linear Accelerator Center	Linear
Nuclear Physics Laboratory	University of Washington Seattle, Washington	Tandem Accelerator	Electrostatic
Oak Ridge National Laboratory	Oak Ridge, Tennessee	Holifield Heavy Ion Research Facility	Cyclotron injecting an electrostatic
Triangle Universities Nuclear Laboratory	Duke University Durham, North Carolina	Cyclograaff Accelerator	Cyclotron injecting an electrostatic

According to DOE and accelerator facility officials, existing accelerator facilities must be upgraded and augmented with new, more powerful machines to aid the quest for deeper probings into matter and the atomic nuclei and/or to prevent or delay facility obsolescence. Major improvements are being made or have been proposed for all of the DOE-supported nuclear physics accelerator facilities. These improvements vary from installation of new radio frequency transmitters for the Bates Center accelerator to the installation of a new linear accelerator at the University of

Washington. Some of the accelerator improvement projects are completed in phases and spread out over several fiscal years. The improvements include upgrades to existing accelerators, purchase of new instruments and equipment, or the addition of new accelerators to connect to those already in operation. The following examples are given to illustrate some of the improvements being made to the nuclear physics facilities.

In fiscal year 1984, Lawrence Berkeley Laboratory completed a project to upgrade the beam transport line connecting the linear accelerator (Superhilac) with a synchrotron (Bevalac). This project included upgrading the beam line and incorporating improved data analysis instrumentation into the beam line. Another upgrade project is scheduled for fiscal year 1986 and involves installation of a new ion source for the linear accelerator and improvements in the hardware associated with the beam transport system.

In fiscal year 1982, Argonne National Laboratory began a project to enlarge its linear accelerator and add a new experimental area. This project--to be completed in fiscal year 1985--was undertaken to improve beam quality and experimental flexibility.

The Yale University accelerator is being upgraded to increase the maximum power from 13.5 MeV to almost 22.5 MeV. The Yale accelerator improvement project started in fiscal year 1984 and is expected to be completed by the end of fiscal year 1986.

FUTURE PHYSICS ACCELERATOR FACILITIES

The High Energy Physics Advisory Panel and the Nuclear Science Advisory Committee have recommended, respectively (and DOE has endorsed), the development of one new high-energy physics accelerator facility and one new nuclear physics accelerator facility to pursue the scientific opportunities beyond the reach of existing facilities or facilities under construction. In addition, the Nuclear Science Advisory Committee advised DOE in December 1983, that the United States should proceed with the planning for construction of a heavy-ion colliding-beam accelerator facility.

DOE has provided research and design funding for the high-energy physics program's facility--the Superconducting Super Collider (SSC)--and the nuclear physics program's facility--the Continuous Electron Beam Accelerator Facility (CEBAF). To date DOE has not approved funding specifically for the heavy-ion colliding-beam accelerator. The three facilities are further discussed below. In addition to these three facilities, at least two other accelerators are being contemplated by DOE laboratories--a high-energy machine for which some preliminary research is being performed and a nuclear physics accelerator for which a formal proposal has been presented to the Nuclear Science Advisory Committee.

Superconducting Super Collider

The need to explore physics phenomena at energies higher than achievable on existing high-energy physics accelerators was addressed in 1983 by the High Energy Physics Advisory Panel. That panel concluded, based on the long development of superconducting accelerator technology, that an SSC was technically feasible. According to DOE officials, if it is completed, the SSC would be in the forefront of world high-energy physics accelerator facilities. In addition, the advisory panel stated that the facility is essential for a strong U.S. program into the 21st Century.

Sometimes called the "ultimate answer machine," the SSC is expected to have a circumference of 60 to 120 miles and generate energies 20 times greater than Fermilab's accelerator. (See pp. 20 and 21.) According to the advisory panel report, the project's concept is to collide protons traveling in opposite directions at combined energy levels up to 40 TeV. The advisory panel report indicated the project would provide a capability not provided by existing or planned high-energy physics facilities.

According to DOE officials, preconstruction research and development for SSC began in fiscal year 1984 and is expected to last 3 years. It is then expected that construction of the project would take 6 additional years and experimental use of the collider facility would begin in 1994. In March 1984 DOE assigned responsibility for the project's preconstruction research and development effort to Universities Research Association, Incorporated. There are four research and development groups involved in various aspects of the accelerator's technology development: Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley Laboratory, and the Houston Area Research Center.

A central design group has been established by the Association to coordinate preliminary SSC technology development and identification of technical site requirements. The group is expected to issue a report to DOE by April 15, 1985. While no specific protocol has been established, DOE has contacted the National Academy of Sciences and the National Academy of Engineering about the possibility of those organizations assisting in the site selection process.

Continuous Electron Beam Accelerator Facility

Interest in a continuous-electron-beam nuclear physics accelerator surfaced in a National Research Council report entitled Future of Nuclear Science. The 1979 Long Range Plan for Nuclear Science prepared by the Nuclear Science Advisory Committee reported a need for a national electron accelerator laboratory. Subsequently, five proposals for a new facility were submitted to and reviewed by a Nuclear Science Advisory Committee Panel on Electron Accelerator Facilities. In 1983 the panel recommended the construction of a 4-GeV continuous-electron-beam accelerator facility (CEBAF) proposed by the Southeastern Universities Research Association. The panel indicated a need for an accelerator with higher energies and higher beam intensities than those currently available in order to better investigate the influence of quarks and gluons on the characteristics and interactions of nuclei.

For fiscal year 1985, DOE provided research and development funding to the Association for a CEBAF facility to be built in Newport News, Virginia. In its fiscal year 1986 budget submission, DOE indicates that CEBAF meets the highest priority need for new accelerator construction in the nation's nuclear physics program. DOE plans to obtain funding to start construction in fiscal year 1987 and, after 6 years of construction, to have CEBAF operational in the 1993-94 time frame.

Relativistic Heavy Ion Collider

The 1983 Long Range Plan for Nuclear Science prepared by the Nuclear Science Advisory Committee recommended a relativistic heavy-ion collider as the highest priority--after CEBAF--for the next major nuclear physics facility to be constructed. This recommendation was made on the basis of "a new scientific opportunity of fundamental importance--the chance to find and to explore an entirely new phase of nuclear matter." The committee recommended an accelerator be built that can provide colliding beams of very heavy ions with energies of about 30 GeV per nucleon in each beam.

In August 1984 Brookhaven National Laboratory submitted a proposal to DOE for construction of a Relativistic Heavy Ion Collider (RHIC). The RHIC would provide head-on colliding beams of heavy ions at about 100 GeV per nucleon in each beam. According to DOE, this collision will allow the study of quarks and gluons. According to the proposal, the construction of the facility represents the natural continuation of the laboratory's role as a center for high-energy physics and nuclear physics research and extends the uses of existing laboratory facilities. Although DOE has not formally approved Brookhaven's RHIC proposal, it has authorized funding for major upgrades to the existing Brookhaven facilities (see p. 20) that would enable the facility's accelerator to be used as an injection source for RHIC.

Other accelerators

Two other accelerators are receiving attention in the science community. The first is a very large linear collider and the second is LAMPF II (see below) proposed by the Los Alamos National Laboratory.

DOE is funding long-range research at the Stanford Linear Accelerator Center to develop the technologies that would be necessary for a very large linear collider. This machine would expand the capabilities of the Stanford Linear Collider now under construction. The goal of this new accelerator would be to provide the capability to collide beams of electrons and positrons with an energy range up to several TeV. Before this accelerator can become a reality, however, numerous components must be designed and developed. No formal proposal has been submitted to the High Energy Physics Advisory Panel or to DOE by Stanford to build such an accelerator.

In December 1984 the Los Alamos National Laboratory submitted a proposal to DOE to construct and operate LAMPF II. This facility would consist of the current linear accelerator (injector), a 6-GeV booster accelerator, and a 45-GeV synchrotron. The Los Alamos proposal indicated LAMPF II would provide facilities for basic research and education to a generation of scientists in the 1990's and well into the next century. If approved, Los Alamos officials believe that LAMPF II construction could begin in fiscal year 1988. LAMPF II has not been endorsed by DOE or the Nuclear Science Advisory Committee.

CHAPTER 3

HOW MUCH DOES IT COST TO BUILD AND OPERATE DOE'S PHYSICS ACCELERATORS?

DOE's support of physics research amounts to hundreds of millions of dollars annually. A major portion of these costs is to operate accelerator facilities and to upgrade these facilities to allow scientists to study the frontiers of physics. DOE's total support for the high-energy physics and nuclear physics programs has increased from $558 million in fiscal year 1983 to an estimated $728 million in fiscal year 1985, including construction costs, capital equipment purchases, and annual operating expenses. Also DOE's two, new planned facilities, if approved, are estimated to cost $4.3 billion to build and about $230 million a year to operate when completed. If substantial increases in federal funding to support these new facilities are not forthcoming, DOE's options appear to be quite limited. The options include closing existing facilities, obtaining greater foreign financial participation, and reducing upgrades to existing facilities.

BUILDING AND OPERATING ACCELERATOR FACILITIES

Conducting high-energy physics and nuclear physics experiments is based on using complex accelerator facilities. For the large facilities, like Fermilab, an extensive amount of research is necessary to develop the concept and the technology upon which the new accelerators are based. The technology must then be engineered and designed to assure reliability and operational efficiency. Because of the complexity and sophistication of modern accelerators, they are designed by developing separate subsystems (i.e., magnets, detection devices, computer systems, etc.) and then combining the various subsystems into a integrated unit. Depending on the complexity of the machines, prototypes or models of the accelerator subsystems may be constructed to demonstrate the workability of the various subsystems in the overall unit. The cost associated with this effort represents a significant portion of the program's cost. For example, in the high-energy physics program, about $90 million in fiscal year 1985 is for conducting research and development on accelerators under construction, developing new accelerator concepts, and improving existing accelerators.

Constructing the high-energy physics accelerators is a major undertaking because of the size and complexity of the facilities involved. To illustrate the magnitude of the effort, DOE constructed the main Fermilab accelerator by digging a 4-mile circular tunnel 30 feet below ground. The 9-foot-wide tunnel was then encased in precast concrete. Inside the tunnel about 1,000 magnets were installed. Subsequently, DOE installed an additional 1,000 specially designed superconducting magnets, which are cooled to a temperature of 4.6-degrees Kelvin.[1] The facilities also use an extensive amount of computer equipment. At Fermilab, DOE's operating contractor uses more than 500 microprocessors throughout the complex. In addition, 34 computers are in operation in a central control system and in experimental areas. Sixty more computers are used to collect data from experiments and equipment. Besides constructing the accelerator, experimental areas and administrative facilities must also be built.

Building nuclear physics accelerator facilities can also be a major undertaking. For example, at the Los Alamos Meson Physics Facility, accelerator construction involved building a machine about one-half mile in length to strict specification. In addition, DOE funded construction for support facilities such as an administrative building, utility extensions, and experimental areas with expensive detection devices. Further, the facility's electronics equipment pool consists of more than 3,000 items costing millions of dollars.

In addition to the construction and capital equipment costs, operating an accelerator facility can be costly. For example, in the high-energy physics program, providing the beams and facility maintenance are expected to account for about $168 million of the $247 million in operating expenses incurred by the accelerator facilities in fiscal year 1985. In this regard, DOE's expenses to operate facilities ranges from $81 million in fiscal year 1985 for Fermilab to less than $1 million for the cyclotron at Texas A&M University. Electricity, labor, and overhead represent the major expense components in providing beams and maintaining the accelerator facilities for both the high-energy physics and nuclear physics programs. At Fermilab, for example, these expense components are estimated to be more than $63 million in fiscal year 1985, or about 80 percent of the facility's operating and maintenance cost. At the Los Alamos Meson Physics Facility, these same cost components are estimated at $31 million, or three-fourths of the facility's total operating cost (excluding experimental research and theoretical studies) for the same year.

DOE'S FUNDING OF HIGH-ENERGY PHYSICS

Since fiscal year 1983, DOE's support of the high-energy physics program has increased 29 percent[2] from $421.9 million to an estimated $545.6 million in fiscal year 1985. In particular, construction and capital equipment costs associated with upgrading and improving existing facilities are expected to increase from $99.7 million in fiscal year 1983 to an estimated $172.7 million in fiscal year 1985. Program operating costs, including research performed at non-accelerator facilities, are also expected to increase from $322.2 million to an estimated $372.9 million in the same period.[3] DOE's investment in accelerator facilities and their associated operating costs are expected to increase in the years ahead as present upgrades are completed and new facilities are built. The following section discusses DOE's total investment in accelerator facilities, its cost to operate them, and what can be expected in the future for new facilities and their operating costs.

---

[1] Kelvin is a scale of temperature based on thermodynamic principles in which zero degrees Kelvin is equivalent to -273° Centigrade.

[2] Adjusted for inflation, this increase amounts to about 22 percent.

Cost to build high-energy physics accelerator facilities

As of January 1985, DOE's investment in these high-energy physics accelerator facilities was nearly $1 billion. The original cost to construct the three facilities totaled nearly $390 million. Since constructing the original facilities DOE has completed various additions and/or upgrades to these facilities at a cost of $603 million. A summary of the cost of the original accelerators and improvements to those accelerators is shown on the next page.

---

[3] Adjusted for inflation, this increase amounts to about 9 percent.

DOE Investment In High-Energy Physics Accelerator Facilities

Facility	Original construction cost[a]	Upgrades and additions[b]	Total
	------(in thousands of then-year dollars)-----		
Brookhaven National Laboratory--Alternating Gradient Synchrotron	$ 30,605	$ 82,290[c]	$112,895
Fermi National Accelerator Laboratory	243,498	294,599	538,097
Stanford Linear Accelerator Center	114,000	226,058	340,058
Total	$388,103	$602,947	$991,050

[a] Includes the cost of accelerators and buildings.

[b] Excludes additions and upgrades currently in progress. These are discussed on pp. 33 to 35. Includes the cost of accelerators, buildings, related equipment, and associated research and development costs.

[c] Excludes research and development costs for which records are not available.

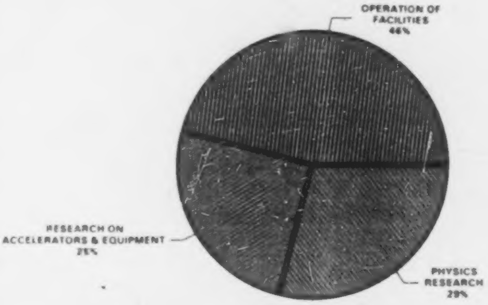
DOE's estimated cost of replacing these facilities in fiscal year 1985 is about $1.8 billion, excluding accelerator-related equipment. DOE estimates the current replacement cost of the equipment to be less than $500 million.

Cost to operate high-energy physics accelerator facilities

DOE's support for operating accelerator facilities, developing new accelerators and related equipment, and carrying out physics research amounted to $373 million in fiscal year 1985. As shown in the chart on the next page, about 71 percent of the program's operating cost in fiscal year 1985, (or $265 million) was for operating facilities and conducting research and development on accelerators and related equipment. The remaining 29 percent (or $108 million) was for physics research.

OPERATING COST OF DOE HIGH-ENERGY PHYSICS PROGRAM

FOR FISCAL YEAR 1985



Source: Prepared by GAO from DOE Financial Information System data

Fermilab, Stanford, and Brookhaven costs accounted for about $247 million, or about two-thirds, of the total program operating cost in fiscal year 1985. The remaining operating cost of about $126 million was for about 90 universities and various other organizations for physics research and accelerator and equipment development. A summary of DOE's operating costs at the three high-energy physics facilities is shown on the next page.

DOE Operating Cost Incurred by High-Energy Physics Accelerator Facilities[a]

Facility	FY 1983	FY 1984	Estimated FY 1985
	(in thousands of then-year dollars)		
Brookhaven National Laboratory--Alternating Gradient Synchrotron:			
Physics research	$ 6,467	$ 6,931	$ 7,218
Facility operations	33,120	35,758	36,265
Accelerator and equipment development	20,537	22,833	14,000
Total	60,124	65,522	57,483
Fermi National Accelerator Laboratory:			
Physics research	7,750	10,144	9,967
Facility operations	75,564	75,524	80,920
Accelerator and equipment development	23,744	31,983	21,200
Total	107,058	117,651	112,087
Stanford Linear Accelerator Center:			
Physics research	10,807	10,735	11,348
Facility operations	43,625	48,330	50,550
Accelerator and equipment development	22,788	15,133	15,450
Total	77,220	74,198	77,348
Total	$244,402	$257,371	$246,918

[a] Includes experimental research and theoretical studies funded by DOE through the facility and performed at other locations. Excludes the cost of separately funded capital equipment purchases and facility maintenance and improvement projects.

High-energy physics upgrades and new facilities

Two of the high-energy physics accelerator facilities have ongoing projects to improve their existing capabilities. The third, Brookhaven's AGS, is being modified to improve the facility's overall research capability. The cost of the Brookhaven AGS modification is shown in the nuclear physics section of this chapter. The following table shows the current improvement projects and DOE's associated costs.

Estimated Cost of DOE Upgrades to High-Energy Physics Accelerator Facilities[a]

Facility	Accelerator and buildings	Equipment	Research and development[b]	Total
	(thousands)			
FERMILAB:				
Tevatron I	$84,000	$94,118	$80,054[c]	$258,172
Tevatron II	49,800	6,000	12,300[c]	68,100
Total	133,800	100,118	92,354	326,272
STANFORD:				
Stanford Linear Collider	115,272	56,467	65,655[d]	237,394
Total	$249,072	$156,585	$158,009	$563,666

[a] Includes DOE funding to other organizations for upgrades to these facilities.

[b] Includes research on detector facilities.

[c] Excludes research prior to construction that cannot be separately identified.

[d] Includes research prior to construction.

In addition to these upgrades, DOE is doing research and development at Fermilab and at other locations on the new SSC facility. DOE estimates the construction and the initial equipment cost of SSC will be about $3.5 billion. DOE anticipates spending another $398 million to $450 million for research and development prior to and during construction and $225 million in pre-operating cost for such functions as testing the various subsystems and staff training. Thus, in total, the cost to build the SSC would be more than $4 billion in fiscal year 1985 dollars.

Beyond the SSC, there are indications DOE's support of long-range research at the Stanford Linear Accelerator Center could lead to a proposal to build a large linear electron/positron collider mentioned by a subpanel of the High Energy Physics Advisory Panel in a July 1983 report.[4] According to a budget official at the Center, about $2.4 million will be spent on this research in fiscal year 1985. DOE has not estimated the cost for such a collider because research is just beginning; it also has not yet received a proposal to build such a machine. Nonetheless, the above mentioned 1983 subpanel report provides some insight into the possible costs involved. The subpanel estimated that a facility of this type could cost from $2.4 billion to $3 billion, if the necessary technology and hardware developments can be accomplished.

---

[4] Report of the 1983 HEPAP Subpanel on New Facilities for the U.S. High Energy Physics Program (DOE/ER-0169, July 1983).

Upgrades and new facilities oftentimes involve additional operating costs. For example, according to DOE budget records, the operating cost of Fermilab is expected to increase from $59 million in fiscal year 1982 (when a fixed target program was in operation at 400 GeV) to more than $80 million in fiscal year 1985, partly as a result of Tevatron I and II and other improvements to the facility.[5] Similarly, construction data sheets for Stanford show the total cost of the facility could increase by $17 million annually as a result of the Stanford Linear Collider. In addition, DOE estimates the operating cost for SSC in its operating phase will be about $202 million annually in 1985 dollars.[6] Thus, assuming full program funding, SSC costs would substantially increase the total operating cost of existing facilities from $247 million in fiscal year 1985 to about $449 million.

DOE'S FUNDING OF NUCLEAR PHYSICS

Nuclear physics accelerator facilities are generally smaller than those for high-energy physics and are, therefore, less costly to build and operate. DOE's funding for operating the entire program has increased 34 percent[7] from $136.9 million in fiscal year 1983 to an estimated $182.9 million in fiscal year 1985, including construction cost, capital equipment purchases, and operating expenses. Like the high-energy physics program, one of the causes for the increase is the upgrading of existing facilities. In this regard, construction and capital equipment costs have increased from $19 million in fiscal year 1983 to an estimated $36 million in fiscal year 1985. Accompanying this increase, program operating costs have also risen from $117.7 million to an estimated

---

[5] Adjusted for inflation, this increase amounts to about 23 percent.

[6] In addition, DOE estimates $42 million annually will be required for capital equipment and about $16 million for annual maintenance and improvements to the facility. Overall, SSC's annual cost during its operating phase will be about $260 million in fiscal year 1985 dollars.

[7] Adjusted for inflation, this increase amounts to about 26 percent.

$146.9 million.[8] DOE also plans to build CEBAF and, if Brookhaven's RHIC proposal is approved by DOE, these new facilities together could be more costly to build and operate than those presently in the program.

Cost of nuclear physics accelerator facilities

As of January 31, 1985, DOE's total investment in the 11 nuclear physics accelerator facilities was about $255 million, excluding the cost of upgrades currently in progress. The initial investment in currently operating nuclear physics accelerators, associated buildings, and instruments and detection devices was about $114 million. Each of the facilities has been upgraded at an aggregate cost of about $141 million. A summary of DOE's investment in the nuclear physics facilities in terms of accelerators, buildings, and related equipment is shown on the next page.

---

[8] Adjusted for inflation, this increase amounts to about 18 percent.

DOE Investment In Nuclear Physics Accelerator Facilities

Laboratory	Original	Upgrades and Additions	Total
	(in thousands of then-year dollars)		
A.W. Wright Nuclear Structure Laboratory/ Yale University	$ 5,334	$ 3,600	$ 8,934
Argonne National Laboratory	4,300	6,700	11,000
Brookhaven National Laboratory	12,410	5,520	17,930
Cyclotron Institute/Texas A&M University	3,000	5,068	8,068
Lawrence Berkeley Laboratory--88-Inch Cyclotron	4,567	7,195	11,762
Lawrence Berkeley Laboratory--Superhilac/Bevalac	15,207	38,074	53,281
Los Alamos National Laboratory	57,000	32,125	89,125
Massachusetts Institute of Technology	5,700	17,011	22,711
Nuclear Physics Laboratory/ University of Washington	380[a]	982	1,362
Oak Ridge National Laboratory	3,573	23,423	26,996
Triangle Universities Nuclear Laboratory/Duke University	2,500	1,143	3,643
Total	$113,971	$140,841	$254,812

[a] Excludes about $2.5 million in funding NSF.

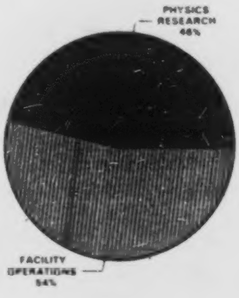
DOE's estimated replacement cost for these facilities is about $725 million in fiscal year 1985 dollars.

Cost to operate nuclear physics accelerator facilities

DOE's cost to operate the nuclear physics program is estimated to be about $147 million in fiscal year 1985, excluding separately funded capital equipment purchases and facility maintenance and improvement projects. As shown in the chart below, about 46 percent (or $68 million) of the program's operating cost was for physics research. The remaining 54 percent (or $79 million) was for operation and maintenance of facilities.

OPERATING COST OF DOE NUCLEAR PHYSICS PROGRAM

FOR FISCAL YEAR 1985



Source: Prepared by GAO from DOE Financial Information System data

About 85 percent (or $125 million) of the program's operating cost (excluding construction and capital equipment purchases) in fiscal year 1985 was incurred by the nuclear physics facilities. The remaining 15 percent (or about $22 million) was provided to about 75 universities and other organizations for physics research at various locations. A cost summary for operating the DOE facilities since fiscal year 1983 is shown on the next page.

DOE Nuclear Physics Operating Cost At Accelerator Facilities[a]

Laboratory	FY 1983	FY 1984	Estimated FY 1985
	(in thousands of then-year dollars)		
A.W. Wright Nuclear Structure Laboratory/ Yale University	$ 2,710	$ 2,968	$ 3,025
Argonne National Laboratory	8,185	9,730	10,700
Brookhaven National Laboratory	7,083	7,138	7,800
Cyclotron Institute/ Texas A&M University	1,022	1,112	1,185
Lawrence Berkeley Laboratory[b]	23,863	28,952	29,555
Los Alamos National Laboratory[c]	41,520	45,725	49,138
Massachusetts Institute of Technology	8,502	9,655	9,795
Nuclear Physics Laboratory/University of Washington	2,018	2,191	2,315
Oak Ridge National Laboratory	8,951	9,644	10,118
Triangle Universities Nuclear Laboratory/ Duke University	951	1,424	1,565
Total	$104,805	$118,539	$125,196

[a] Includes experimental research and theoretical studies funded by DOE through the laboratory and performed at other locations. Excludes separately funded capital equipment purchases and facility maintenance and improvement projects.

[b] Includes cost of operating the 88-inch Cyclotron and the Bevalac accelerator.

[c] Includes DOE defense program funding of $3 million in fiscal years 1983 and 1984, and $3.1 million in fiscal year 1985.

Nuclear physics upgrades and new facilities

At the present time, each of the nuclear physics accelerator facilities is upgrading its experimental capabilities. DOE's estimated cost of these upgrades is $57 million. A summary of the upgrades by facility is shown on the next page.

DOE Cost of Upgrades to Nuclear Physics Accelerators

Laboratory	Total estimated cost[a]
	-----(in millions)---
A.W. Wright Nuclear Structure Laboratory/Yale University	$ 11.5
Argonne National Laboratory	13.7
Brookhaven National Laboratory	12.3
Cyclotron Institute/Texas A&M University	-0-
Lawrence Berkeley Laboratory	2.8
Los Alamos National Laboratory	3.8
Massachusetts Institute of Technology	1.9
Nuclear Physics Laboratory/University of Washington	9.2
Oak Ridge National Laboratory	1.4
Triangle Universities Nuclear Laboratory/Duke University	.4
Total	$ 57.0

[a] Includes DOE costs incurred and to be incurred. Other upgrades may be ongoing that are not funded by DOE. For example, although upgrades at Texas A&M University is shown to be zero, a new accelerator is being added at a cost of $7.3 million with funds provided by state and private donors.

In addition to these upgrades, DOE plans to build CEBAF at a cost which is expected to be about $220 million in fiscal year 1985 dollars. To better define construction costs, DOE is spending $3.5 million in fiscal year 1985 operating funds for architect/engineering work and research and development on components. Though DOE envisioned starting construction in fiscal year 1986, the Office of Management and Budget did not include the project in the President's fiscal year 1986 budget request. With the start of construction now planned for fiscal year 1987 and operations scheduled to begin in the 1993-94 time frame, DOE estimates that CEBAF's annual operating cost would be about $30 million to $35 million in fiscal year 1985 dollars.

If DOE were to support the Brookhaven National Laboratory's proposed RHIC facility, construction would cost about $230 million, including the cost of research and equipment. The Director of the nuclear physics program estimates the annual operating cost of RHIC to be about $50 million in fiscal year 1985 dollars. Assuming construction funds for both CEBAF and RHIC are provided and no existing facilities are shut down, DOE's nuclear physics accelerator operating expenses could increase more than 60 percent from $125 million to about $205 million in 1994 (fiscal year 1985 dollars) after construction of the new facilities.

In addition to these facilities, the Los Alamos National Laboratory's proposed LAMPF II, if approved, would be the most expensive of the new nuclear physics facilities now under consideration. The construction cost of LAMPF II is expected to be about $450 million in fiscal year 1985 dollars. The proposal has not been approved by DOE or the Nuclear Science Advisory Committee, and DOE has not estimated the operating cost of LAMPF II.

FUNDING OF PLANNED PHYSICS FACILITIES

Accelerator facility officials believe that DOE is maximizing the amount of physics research and the training of physicists by building new accelerator facilities and continuing to operate the existing ones. However, DOE believes that to the extent existing facilities become obsolete, they should be shut down. If some existing facilities are not shut down, the large additional cost of operating the new facilities and the federal budget deficit will make it difficult for DOE to obtain full federal funding for new and existing facilities.

The Chief of the Program Operations Branch for the high-energy physics program told us DOE is developing projections on total program cost that include SSC. Because of the tentative status of the projections, this official did not reveal the specifics of the various projections. The Director of the nuclear physics program provided us his views on financing the program, cautioning that his views do not represent a formal commitment by DOE. On the basis of our work, there appear to be three basic options available to DOE, separately or in combination, in the event full funding is not forthcoming.

--Eliminate construction upgrades and improvements in existing facilities to provide funds for operating new facilities.

--Close one or more of the existing facilities to free operating funds for new facilities.

--Obtain nonfederal funding to help support the program.

The first option--eliminating construction upgrades and improvements to existing facilities--appears to be somewhat limited for the high-energy physics program because annual construction and capital equipment funds are currently less than the estimated annual operating cost of SSC. For example, construction and capital equipment funds appropriated by the Congress for the three existing high-energy physics facilities have ranged between $105.2 million in fiscal year 1983 and $172.7 million in fiscal year 1985, far less than the estimated $260 million to operate the SSC (including separately funded capital equipment costs and facility maintenance projects). In addition, if upgrades and improvements were eliminated for the existing facilities, DOE contends these facilities may no longer be capable of exploring the frontiers of physics in areas not covered by the SSC. As such, the quality of experiments conducted at those facilities may be adversely affected. For the nuclear physics program, construction and capital equipment funds for upgrades and improvements of $18 million to $36 million annually have been appropriated by the Congress since fiscal year 1983. While funds of this magnitude may be sufficient to offset CEBAF's $30 to $35 million operating cost, such funds would not offset the combined estimated operating cost of CEBAF and RHIC, which together would total $80 to $85 million annually.

The second option involves closing one or more of the existing physics facilities to provide operating funds for the new ones. Notwithstanding the construction cost, this option has the advantage of allowing DOE to operate the SSC with no overall increase in the program's operating cost. However, by closing all three existing facilities, DOE contends it would be eliminating several areas of scientific investigation that will not be covered by the new facility. The nuclear physics program has more facilities to choose from in deciding which facilities to close. However, this option is still limited. Both of the Lawrence Berkeley Laboratory accelerator facilities and the Los Alamos Meson Physics Facility would have to be closed to offset the combined operating cost of CEBAF and RHIC. If DOE chooses not to close either of these facilities, even closing all of the other facilities, including the university facilities, will be inadequate to offset the additional operating cost of CEBAF and RHIC.

The third option--obtaining nonfederal funding--has the advantage of allowing DOE to operate more facilities without increasing federal support. The cost of upgrading existing facilities and constructing new facilities such as SSC has increased awareness of the need for international cooperation between countries as the cost of high-energy physics machines increase. For example, in January 1982 the High Energy Physics Advisory Panel recommended that the United States ". . . entertain the possibility of major bilateral accelerator construction projects with Europe or Japan, if they are cost effective and have strong physics motivation."[9] To date DOE has not participated in the construction of any foreign accelerators. Nonetheless, in an effort to offset some of SSC's construction and equipment costs, efforts are underway to obtain foreign participation. Canada and Japan are viewed as potential partners in the SSC project. No formal agreements have been reached, however, and DOE believes the federal government must first make a commitment to SSC before participation by other countries can be seriously pursued.

---

[9] Report of the Subpanel on Long Range Planning for the U.S. High Energy Physics Program of the High Energy Physics Advisory Panel (DOE/ER-0128, January 1982).

CHAPTER 4

WHAT BENEFITS ARE BEING DERIVED FROM DOE'S HIGH-ENERGY PHYSICS AND NUCLEAR PHYSICS ACCELERATORS?

According to DOE and accelerator facility officials, experiments conducted using DOE's high-energy physics and nuclear physics accelerators have resulted in many important discoveries related to the structure and properties of atomic nuclei and subnuclear particles. DOE's funding of high-energy physics and nuclear physics research and accelerator facilities has also directly contributed to the education of future physicists. Further, DOE's programs, according to DOE and laboratory officials, have contributed to understanding the origin of the universe, have promoted accelerator use in medicine and other sciences and have indirectly led to industrial uses of the equipment and technology developed for the accelerators. DOE officials also recognized the societal value of basic research even though the benefits may be esoteric and difficult to quantify.

PHYSICS ACCOMPLISHMENTS

Experimental results of the 1970's and 1980's have refined and consolidated the standard model of physics (see pp. 2 and 3). According to DOE and accelerator facility officials, the three DOE-funded high-energy physics accelerator facilities contributed in a major way to that advance. These officials described several major high-energy physics accomplishments resulting from experiments conducted at the DOE-funded high-energy physics accelerators.

--Experiments in the late 1960's on the Stanford linear accelerator demonstrated that the heart of the atomic nucleus, the proton, is comprised of smaller particles, known as quarks.

--In 1975, a particle called the tau lepton was discovered during an experiment on the SPEAR accelerator at Stanford. The discovery of this particle suggested the existence of the top and bottom quark. Later, experiments conducted at Fermilab proved the existence of the bottom quark.

--Experiments conducted on the SPEAR accelerator in 1974 confirmed the existence of the charm quark.

Some of the experimental results from the high-energy physics accelerators have received international recognition. For example, in 1974, scientists using the Brookhaven AGS accelerator and the Stanford SPEAR accelerator independently discovered a new particle which was called the J/psi. This discovery won Nobel Prizes in 1976 for Sam Ting of the Massachusetts Institute of Technology and for Burton Richter, now the Director of the Stanford Linear Accelerator Center, and was important because its existence supports the "standard model" and later led to several other discoveries. In addition, a 1980 Nobel Prize was awarded to Princeton University Professors Val Fitch and James Cronin for a discovery related to the decay of subatomic particles. This discovery was based on experimental work performed on the Brookhaven AGS accelerator and was important because it contradicted one of the most basic physics theories at that time. A detailed list of high-energy physics achievements--developed by DOE in 1979--is included as appendix III. A DOE-provided update for 1979 through 1984 is included as appendix IV.

According to DOE nuclear physics program officials, nuclear physicists are adding to man's knowledge of the interactions, properties, and structures of atomic nuclei, and each of the 11 facilities has made important contributions to nuclear physics. For example, 26 new nuclei have been discovered over the last 15 years on the Brookhaven electrostatic accelerators. In addition, experimental observations have been made at Lawrence Berkeley Laboratory's Bevalac facility of nuclear matter with densities three to four times greater than ordinary matter. Researchers observed that at those densities, nuclei behave in many ways like a liquid. The facility has also raised nuclear matter to temperatures hotter than those at the center of the sun. Two detailed lists of nuclear physics accomplishments--compiled by DOE--are included as appendixes V and VI.

The high-energy physics goal of understanding the forces of nature and the ultimate structure of matter also relates to astrophysics. Astrophysics is the branch of astronomy dealing with the physical and chemical properties of celestial bodies. According to DOE and accelerator laboratory officials, achievement of the high-energy physics objectives may contribute to understanding the origins of the universe.

The high-energy and nuclear physics accelerators also provide a training ground for physicists. While education is an important by-product of the high-energy physics accelerators, the emphasis on education of physicists is somewhat less than that at the nuclear physics accelerators. However, at hearings before the Subcommittee on Energy Development and Applications, House Committee on Science and Technology on February 22, 1984, DOE officials estimated that about 150 doctoral degrees are conferred annually on the basis of work done at DOE's high-energy physics facilities. The Chairman of the Nuclear Science Advisory Committee told us that education is the primary mission of the four university-based nuclear physics accelerators and an important goal at the seven national nuclear physics accelerator facilities. According to data provided by DOE at the same February 1984 hearings, 60 to 80 doctoral degrees are conferred each year on the basis of research conducted at nuclear physics accelerator facilities in the United States.

INDUSTRIAL APPLICATIONS

According to DOE and accelerator officials, although not an objective of DOE's high-energy physics and nuclear physics programs, many industrial applications have resulted from developments in accelerator physics. These applications include industrial uses of superconducting magnets and materials testing. In addition, commercial accelerators used in medical and industrial applications were developed on the basis of high-energy or nuclear physics accelerator research.

Two high-energy physics facilities have developed superconducting magnets for their accelerators. Application of this knowledge has been explored for more than 10 years at Brookhaven National Laboratory for electric power transmission. Brookhaven officials now believe they are close to a viable system of underground power transmission that is based on superconductivity. In January 1985 a private corporation submitted a proposal to the Empire State Electric Energy Research Corporation (an association of electric utilities in New York) to manufacture and test a transmission cable using the technology developed at Brookhaven.

In addition, Brookhaven and Fermilab officials stated that superconducting technology developed at those facilities has been used in Japan on an experimental train. Superconducting magnets propel the train and also allow the train to float above similar magnets in the "track." Speeds of up to 321 miles per hour have been attained in tests.

The Director of Fermilab also cited the current use of commercial (nonresearch) accelerators as a result of the DOE accelerator physics programs. Specific applications include the inspection of thick metal vessels and pipes, the sterilization of food, and the disinfection of sewage that is to be recycled as fertilizer. Commercial accelerators are also used in the manufacture of integrated circuits. According to the director, over 1,000 such accelerators are currently in use, annually producing circuits for about $8 billion in sales of calculators, computers, and microprocessors. Other facility officials cited cryogenic refrigeration[1] systems, high-speed computers, microwave science, high-level radiation handling equipment, and precision lasers as spin-offs from the accelerator programs.

MEDICAL AND OTHER SCIENTIFIC APPLICATIONS

In addition to the accelerator facilities' primary mission of experimental physics, several of the facilities also use the accelerators for medical purposes and other science research. For example, neutrons produced by the Fermilab high-energy physics accelerator have been used to treat about 1,000 cancer patients over a recent 5-year period. Similarly, heavy-ion beams produced by the Bevalac nuclear physics accelerator have been used to treat about 15 patients per day during 1984. Treatments utilizing the Fermilab and Bevalac beams have been effective in reducing or eliminating some malignant tumors. The Director of Fermilab stated that about 1,000 commercial accelerators also treat cancer patients in the United States. In recent years commercial accelerators have treated about 350,000 patients per year.

---

[1] Cryogenic refrigeration is used to obtain near absolute zero temperatures (about -273° Centigrade).

The production of radioactive isotopes[2] was also cited by DOE and accelerator facility officials as an application of DOE's accelerators. Radioactive isotopes are used to treat cancer patients, test functional performance of organs and diagnose illnesses. Accelerator beams at Brookhaven, LAMPF, and the Lawrence Berkeley cyclotron are currently used to produce isotopes for medical uses. Radioactive isotopes are also produced by commercial accelerators.

A specific example of a medical application of DOE accelerators occurred in 1976, when DOE was granted a patent for a Brookhaven development.' Using a radioactive isotope called technetium-99, red blood cells can now be freeze-dried and stored for up to 5 months. Previously, blood had to be withdrawn and labeled just prior to chemical study--a laborious and inconvenient task, according to Brookhaven officials. These officials estimated that sales of the technetium-99 isotope would be about $200 million in 1985.

Some DOE accelerators have been taken over partially or completely for research involving other sciences. For example, when a high-energy physics accelerator--the Argonne Zero Gradient Synchrotron--was shut down in 1979, the injector portion of the facility was transferred to a new research program. The resulting Intense Pulsed Neutron Source facility produces beams of neutrons for physics, chemistry, biology, and materials science experiments that study the position and motion of atoms.

In addition, an electrostatic accelerator at Oak Ridge National Laboratory is an example of a DOE-funded nuclear physics accelerator which is now used for other purposes. This accelerator was built in 1960 by DOE's nuclear physics program. DOE's construction of the Holifield Heavy Ion Research Facility in Oak Ridge made this accelerator expendable and it was transferred to DOE's atomic physics program; it is now used for fusion energy, astrophysics, and solid state physics research.

Accelerator-based facilities have also been developed for research in biology, chemistry, medicine, solid-state physics, and materials science using ultraviolet and x-ray beams. National facilities involved in these sciences are operating at the Brookhaven National Synchrotron Light Source and the Stanford Synchrotron Radiation Laboratory (utilizing the SPEAR accelerator). A third such facility has been proposed by Argonne at an estimated $120 million construction cost.

---

[2] An isotope is one of two or more atoms having the same number of protons (which makes them the same chemical element) but having a different number of neutrons (which gives them different atomic weights).

SOCIETAL VALUE

The physics community often refers to the societal value of their fields. This value is--as with any basic science--impossible to fully quantify or, for that matter, render a judgment as to the significance of its worth. In our 1980 report on high-energy physics,[3] DOE officials provided us with the following view:

> "In the past two hundred years, mankind has found some truly fundamental causes for what is going on in the natural world and we have learned to penetrate below the surface of the phenomena that are ordinarily observed around us. Basic science has searched for and has found a regular world beneath the seemingly irregular flow of natural events and has studied its laws and interrelations. This search goes on and reaches ever deeper layers of nature finding at the same time new and unexpected forms of natural events. High energy physics is a spearhead in this endeavor, it tries to reach the deepest level of the material world.
>
> Basic science is one of the cornerstones of our Western civilization. No other civilization has created anything like it. It is probably the major contribution of our time to the great creations of the human spirit. It is one of the positive constructive elements in the time when so many values are undermined and overthrown.
>
> A vigorous basic science creates a spiritual climate which affects the whole intellectual life of the Nation by its influence on the way of thinking and by setting standards for many other intellectual activities. Applied sciences and technology adjust themselves to the highest intellectual standards which are strived for in the basic sciences. It is the style, the scale, and the level of scientific and technical work in pure research that attracts some of the most inventive spirits and brings the most active scientists to those countries where science is at its highest level. This is why many outstanding scientists have moved to the United States from other countries in the recent decades.
>
> The case for generous support for pure and fundamental science is as simple as this. Fundamental research sets the standards of modern scientific

---

[3] Increasing Costs Competition May Hinder U.S. Position of Leadership in High Energy Physics (EMD-80-58, Sept. 16, 1980).

> thought; it creates part of the intellectual climate in which our modern civilization flourishes. It pumps the lifeblood of ideas and inventiveness not only into the technological laboratories and factories, but also affects other cultural activities. It is a most vital and active part of our intellectual life, a part which we all should regard with pride as one of the highest achievements of our century."

In a 1982 paper,[4] the Director of Fermilab stated that the knowledge and acceptance of science's cultural value is necessary in maintaining healthy science programs, as follows.

> "The earliest drive towards explanations of how things work was a cultural one. And it is the cultural appeal which has attracted the best minds into science. Whereas the guarantee of an economic and clean source of energy may be the most crucial scientific problem of our day, the bright high school student will more often be drawn to science by the puzzle of neutrino mass, antimatter and the big bang theory of creation. Not only is pure science a recruiting factor but its success sets standards and reaffirms confidence among workers throughout the spectrum of science.
>
> "If the cultural value of these sciences is not given its required weight in long range science policy planning, we will have a second rate enterprise--innovation and progress will slow . . . To appreciate the power of the cultural drive, one must spend enough years with undergraduates or, even more dramatically, with the high school students such as those who flood my laboratory each Saturday morning. It is out of these culturally agitated young people that the genius will come to solve our many problems in unexpected ways."

---

[4] Viewpoint From Fundamental Science, by Leon M. Lederman, Revised Apr. 15, 1982.

MARK O. HATFIELD, OREG., CHAIRMAN

TED STEVENS, ALASKA
LOWELL P. WEICKER, JR., CONN.
JAMES A. MC CLURE, IDAHO
PAUL LAXALT, NEV.
JAKE GARN, UTAH
THAD COCHRAN, MISS.
MARK ANDREWS, N. DAK.
JAMES ABDNOR, S. DAK.
ROBERT W. KASTEN, JR., WIS.
ALFONSE M. D'AMATO, N.Y.
MACK MATTINGLY, GA.
WARREN RUDMAN, N.H.
ARLEN SPECTER, PA.
PETE V. DOMENICI, N. MEX.

JOHN C. STENNIS, MISS.
ROBERT C. BYRD, W. VA.
WILLIAM PROXMIRE, WIS.
DANIEL K. INOUYE, HAWAII
ERNEST F. HOLLINGS, S.C.
THOMAS F. EAGLETON, MO.
LAWTON CHILES, FLA.
J. BENNETT JOHNSTON, LA.
WALTER D. HUDDLESTON, KY.
QUENTIN N. BURDICK, N. DAK.
PATRICK J. LEAHY, VT.
JIM SASSER, TENN.
DENNIS DE CONCINI, ARIZ.
DALE BUMPERS, ARK.

J. KEITH KENNEDY, STAFF DIRECTOR
FRANCIS J. SULLIVAN, MINORITY STAFF DIRECTOR

United States Senate
COMMITTEE ON APPROPRIATIONS
WASHINGTON, D.C. 20510

November 25, 1984

Mr. Charles A. Bowsher
Comptroller General of
the United States
General Accounting Office
441 G Street
Washington, D. C. 20548

Dear Mr. Bowsher:

The annual cost of the Department of Energy's nuclear physics and high energy physics programs is about $750 million. A sizeable portion of this cost is dedicated to the operation, maintenance and frequent upgrading of several large particle accelerators. During the past year, the Department requested about $250 million to construct a new facility, the Continuous Electron Beam Accelerator Facility (CEBAF). The Department also has preliminary plans for building another much larger accelerator, known as the super-conducting super collider. This device--a circular beam track with a circumference of between 60 and 120 miles--is expected to cost as much as $4 billion to construct and may cost more.

With these proposals in mind, the Subcommittee on Energy and Water Developoment of the Senate Committee on Appropriations is becoming increasingly concerned about the need for larger, more costly nuclear and high energy physics facilities. I am therefore asking the General Accounting Office to develop information related to the Department's nuclear and high energy physics programs and facilities. As part of that effort, I am requesting that GAO:

--compile an inventory of accelerators that have been built or are planned in the United States,

--identify the construction, operation, and maintenance costs associated with these accelerators, so that a clearer view of the appropriations that will be required to support the cummulative inventory of facilities and projects in future years will be available to the Subcommittee; and

--determine what benefit is being derived from the construction and operation of these accelerators.

Because the Subcommittee is concerned about upcoming funding requests for nuclear and high energy physics facilities, the Subcommittee will need this information in time for use during deliberations on the Department of Energy's Fiscal Year 1986 budget request--probably around April 1, 1985.

If you have any questions concerning this matter, please contact Mr. Proctor Jones of the Subcommittee staff.

Sincerely,

J. Bennett Johnston
Ranking Minority Member

JBJ:bcg

ACCELERATOR CAPABILITIES

The table on the following page was prepared by GAO based on information provided by DOE to show a representative mix of the capabilities of the accelerators supported by its nuclear physics program. As shown in the table, an accelerator can accelerate less massive particles to higher energies than it can accelerate the more massive particles. For example, the accelerator at Yale University can accelerate particles with an atomic mass unit (AMU)[1] of 1 to an energy of 27 MeV. If the particle to be accelerated has an AMU of 120, then the Yale machine could accelerate that particle only to 2 MeV per AMU.

---

[1] Atomic mass unit (AMU) is a unit of measure used to compare the mass of atomic particles where AMU 1 is approximately equal to the mass of one proton.

SELECTED CAPABILITIES OF DOE-SUPPORTED NUCLEAR PHYSICS ACCELERATORS

Facility	Location	Accelerated Particles	
		Mass (AMU)	Maximum Energy (MeV per AMU)
A.W. Wright Nuclear Structure Laboratory Yale University	New Haven, Connecticut	1 16 120	27 8 2
Argonne Tandem/Linac Accelerator Argonne National Laboratory	Argonne, Illinois	1 16 127	30 20 6
Tandem/AGS Brookhaven National Laboratory	Upton, New York	12 to 32 63 238	14,000[a] 2 0.5
Cyclotron Institute Texas A&M University	College Station, Texas	1 12 40	55 26 8
88-Inch Cyclotron Lawrence Berkeley Laboratory	Berkeley, California	1 16 84	55 35 6
Superhilac/Bevalac Lawrence Berkeley Laboratory	Berkeley, California	1 56 238	4,900 2,100 960
Clinton P. Anderson Meson Physics Facility Los Alamos National Laboratory	Los Alamos, New Mexico	1	800
Bates Linear Accelerator Massachusetts Institute of Technology	Middleton, Massachusetts	electrons	750 MeV maximum energy
Nuclear Physics Laboratory University of Washington	Seattle, Washington	1 16	18 5
Holifield Heavy Ion Research Facility Oak Ridge National Laboratory	Oak Ridge, Tennessee	10 197	26 3
Triangle Universities Nuclear Laboratory	Durham, North Carolina	1 4	32 24

[a] Upon completion of transfer line project in FY 1986.

US MAJOR ACCOMPLISHMENTS IN HIGH ENERGY PHYSICS SINCE 1945

June 1979

Prepared by:

Division of High Energy Physics
US Department of Energy
Washington, D.C. 20545

FOREWORD

This chronological list is the result of an effort to give a short account of major achievement milestones in the evolution of high energy physics in the United States since 1945. Assembled in this form, it illustrates the rapid development of our conceptions of the basic nature of matter and energy, the importance of technological developments to this field, and the strong interleaving of experimental and theoretical discoveries.

The listing is meant to include only major highlights and the selection of items is necessarily somewhat arbitrary. It is also likely that new discoveries and the power of hindsight would result in a different selection in future such lists.

US Major Accomplishments in High Energy Physics Since 1945

1945	Synchrocyclotron principle (phase stability) suggested, removing the last technical barrier to unlimited particle energies attainable by orbital or linear accelerators.
1946	184" synchrocyclotron began operation with 350 MeV protons at what is now the Lawrence Berkeley Laboratory. This machine, which by 1957 had reached 720 MeV, was used to study in detail the pions which were discovered in cosmic rays in 1947.
1947	Muon identified as lepton, i.e., as a particle which does not experience the strong nuclear force. First observed in the late 1930's, the muon had been thought to be the meson carrier of the strong force postulated by Yukawa in 1935. The finding that it did not interact strongly led to a successful search for a heavier particle, the pion, which decayed into the muon. The pion was found to interact strongly and hence identified as the Yukawa meson.
1948 a	Universality of weak interactions suggested, i.e., weak interaction recognized as a fundamental force. This force is responsible for the decays of radioactive nuclei, of muons and many other particles and for neutrino interactions with matter, which have been extensively studied in the 1970's and are important in astrophysical processes.
1948 b	Quantum electrodynamics renormalized. Stimulated by measurement of the Lamb shift, a very small splitting of two quantum states of the hydrogen atom which had been thought to have identical energies, new calculations showed how to resolve the long-standing divergence problems of QED and established it as the correct relativistic theory of the electromagnetic force. This theory has withstood 30 years of extremely rigorous experimental testing, and is still our most precise field theory, serving also as a model for other gauge theories presently being developed for the strong interaction. J. Schwinger shared the 1965 Nobel Prize for his contributions to QED.
1949 a	Berkeley Synchrotron began operation with electrons of 330 MeV. This accelerator, which utilized the principle of phase stability, produced in its first year the discovery of the neutral pion and played an important role in determining the properties of pions.

1949 b Neutral pion discovered at the Berkeley Synchrotron, completing the triplet of charge states, π^+, π^-, and π^0, which mediate the strong force binding neutrons and protons in atomic nuclei.

1949 c Feynman diagram approach to field theory invented, and applied to quantum electrodynamics. This graphical way of describing interactions has been a powerful language for both quantitative and qualitative calculations in all areas of particle physics and in other fields of physics as well. Feynman shared the 1965 Nobel Prize for his work on quantum electrodynamics.

1950 High Power Klystron first used in the Stanford Mark II linear accelerator. These power amplifiers are the heart of modern electron accelerators, supplying radiofrequency power to the cavities which accelerate the electrons.

1951 Resonant beam extraction developed for accelerators. This technique of extracting the particle beam from the machine in a slow "spill" is crucial for many electronic experiments.

1952 a Associated production hypothesis proposed: that the Λ and K particles, which had been discovered in cosmic ray interactions, are produced only in association with each other. The hypothesis was experimentally confirmed and led to the discovery of a new property of certain particles called "strangeness" (see 1953 e).

1952 b Δ discovered at the Chicago Cyclotron. The delta was the first detected particle "resonance", or very short-lived particle formed as a resonant combination of two or more other particles, in this case the pion and proton. Many other resonances have since been discovered, leading physicists to seek a more fundamental set of building blocks of matter (see for example 1961 a and 1964 b).

1952 c Strong focusing (alternating gradient) principle discovered. This method of using magnetic field gradients alternating in direction to focus a beam of charged particles had two important consequences: it greatly reduced the cost of accelerators by allowing much smaller magnet apertures (since the beam could be focused to a small diameter), and it provided a means of transporting extracted or secondary beams (produced by interactions of the primary beam with a target) to experimental apparatus located far from the accelerator.

1952 d *Cosmotron began operation* at Brookhaven National Laboratory with 2.3 GeV protons, later raised to 3 GeV. The first multi-GeV accelerator, it had sufficient energy to produce the strange particles which had been observed in cosmic rays. The associated production hypothesis was confirmed, several additional strange particles were discovered and their properties studied.

1953 a *CPT Theorem proved* - any local field theory is invariant under the combined operation of particle-antiparticle exchange (C), mirror reflection (P), and time reversal (T), if the theory of relativity is correct. This very general invariance principle has important consequences, e.g., that a particle and its antiparticle have equal masses and lifetimes.

1953 b *Bubble chamber invented* at the University of Michigan. This device records the passage of a charged particle as a trail of small bubbles in a medium such as liquid hydrogen. Photographs of the tracks allow detailed studies of the interaction of an incident particle in the liquid and any subsequent decay processes. The bubble chamber became the dominant experimental high energy physics technique for many years and is still a powerful tool for exploratory research and very detailed studies of complex processes.

1953 c *Σ^+ discovered* in a cosmic ray experiment: the first member of a new family of "hyperons" similar to the lambda hyperon, a strange baryon. The other two members of the sigma family were subsequently discovered at the Cosmotron.

1953 d *Experimental confirmation of associated production* of strange particles, at the Cosmotron (See 1952 a).

1953 e *Strangeness quantum number proposed* to explain associated production. Hyperons and kaons have a charge-like property, called "strangeness" for the "strange" behavior of strong production and weak decay. Strangeness is conserved in strong interactions such as those which produce lambdas and kaons. However, these particles are not massive enough to decay to other strange particles, so their decays must proceed through the weak interaction which does not conserve strangeness. (Heavier strange particles have since been discovered which do decay via the strong interaction.)

1954 a Bevatron began operation at Berkeley with 4.9 GeV protons, later increased to 6.2 GeV. The antiproton and many other particles and antiparticles were discovered with this accelerator.

1954 b Ξ^- (Ksi) discovered: the first of a pair of hyperons with two units of strangeness.

1954 c Yang-Mills theories - a method of constructing field theories invariant under a local gauge group was invented. This class of "gauge theories" has been important in theoretical developments such as recent advances in developing a theory of strong interactions (see 1973 b).

1954 d Derivation of dispersion relations from quantum field theory. These relations provided support for field theory, independent of perturbation theory (the usual method of field theory calculations based on successive approximations), and formed a basis for a detailed understanding of pion physics.

1954 e Cornell BeV Synchrotron began operation. This 1.3 GeV electron accelerator demonstrated the practical application of the strong focusing principle.

1955 a Discovery of the antiproton at the Bevatron, confirming the 1928 prediction of relativistic quantum mechanics that for every basic particle there must be an antiparticle, i.e., a particle with all charge-like quantum numbers (such as electric charge, strangeness, baryon number) reversed in sign. E. Segre and O. Chamberlain received the 1959 Nobel Prize for the discovery.

1955 b K_L^0 predicted. The neutral K meson was predicted to decay through two states, K_S^0 and K_L^0, with different decay modes and lifetimes. Each would be a quantum mechanical mixture of particle and antiparticle but a definite state of CP (see 1953 a).

1955 c First indications of structure within the proton, now understood to be composed of quarks. Studies of large angle scattering of electrons by protons showed that the proton had a finite size and hence must have structure. Hofstadter shared the 1961 Nobel Prize for this and related work.

1956 a Neutrino observed, confirming the hypothesis of its existence made by Pauli in 1933. The existence of an uncharged, massless particle having only weak interactions seemed essential to an understanding of nuclear beta decay, yet these properties made its experimental observation a very difficult matter until recent high energy accelerators were built.

1956 b	Parity violation predicted to occur in weak interactions. One of the most challenging problems of the 1950's was the so-called τ-θ puzzle; there seemed to be two particles which were identical in every respect except that they decayed into states of opposite parity. A radical alternative was suggested, that they were in fact the same particle (the K^+) but parity was not conserved in the weak interaction which governed its decay. It had long been assumed that parity, the mirror reflection operation, was conserved in all physical processes. Parity violation was quickly confirmed in a nuclear physics experiment, and T. D. Lee and C. N. Yang won the 1957 Nobel Prize for their bold prediction.
1956 c	K_L^0 (long-lived neutral kaon) discovered at the Cosmotron, confirming the prediction of 1955 that there be a long and a short-lived state. The short-lived state K_S^0 had long been known, from the earliest cosmic ray "vee" particles. These mixtures of particle and antiparticle are unique to the neutral kaons.
1958 a	V-A theory of weak interactions proposed, explicitly incorporating parity violation. This theory, extended in 1963 to include strangeness-changing processes, has successfully explained a wide variety of weak interaction processes.
1958 b	Neutrino helicity determined. The massless neutrino always has its spin directed opposite to its momentum; it is said to be "left-handed" or to have negative "helicity". (The anti-neutrino has positive helicity). The observation of the neutrino's helicity was an important confirmation of the V-A theory.
1959	72-inch bubble chamber began operation at the Bevatron with a liquid hydrogen fill. Luis Alvarez received the 1968 Nobel Prize for particle discoveries using this device and the extensive system developed to analyze the photographic data.
1960 a	Brookhaven Alternating Gradient Synchrotron (AGS), a strong focusing accelerator, began operation with protons of more than 30 GeV, a factor of five higher than previous machines. Among the most important discoveries made at the AGS are the ν_μ, the Ω^- and the Ψ/J. (1962 a, 1964 a, 1974 a).
1960 b	Y* (1385) discovered at the Bevatron, the first of a family of pion-hyperon resonances.
1960 c	Spontaneous symmetry breaking proposed as the determining mechanism by which the strong interactions manifest themselves in nature. This work has had an influence on current thinking about quark interactions and on the efforts to unify all interactions within a single theory.

1961 a	SU(3) theory proposed independently by scientists in the US and in England. Known mesons and baryons were grouped into families, in a manner analogous to the periodic table of the elements. SU(3) led directly to the idea of quarks (1964 b). M. Gell-Mann received the 1969 Nobel Prize for this and other work.
1961 b	η (eta) meson discovered at the Bevatron, completing one of the SU(3) families (that of the spin 0, odd parity mesons) and thus giving important support to the theory.
1961 c	ρ (rho) meson discovered at the Cosmotron, the first pion resonance, and the first member of a new SU(3) family, the spin 1 nonet.
1961 d	ω (omega) meson discovered at the Bevatron, a pion resonance which occurs as a quantum mechanical mixture with the ϕ meson (1962 c).
1961 e	K* (890) discovered at the Bevatron, the first strange meson resonance, also a member of the spin 1 nonet.
1961 f	Matched long straight sections proposed for circular accelerators. A way was shown to insert straight sections without disturbing the operation of the machine, thus greatly enhancing its utility. Straight sections allow efficient systems for injection and extraction of the beam at high energy and are very important for colliding beam machines.
1962 a	ν_μ discovered at the AGS: a new type of neutrino, associated with the muon, The experiment showed that neutrinos produced in association with muons are distinct from those produced with electrons.
1962 b	On-line digital computer applied to data handling for a large array of scintillation counters, allowing much higher complexity of experimental apparatus and a higher rate of data acquisition. This technique and its further developments led to the present generation of very powerful electronic experimental facilities.
1962 c	ϕ (phi) meson discovered at the AGS, the first kaon resonance and a member of the spin 1 family, this meson mixes with the ω. The ϕ is now understood as an $s\bar{s}$ combination of quarks analogous to the $c\bar{c}$ quark combination which forms the J/Ψ (see 1964 b and 1974 a).
1962 d	Application of Regge theory to high energy physics: a sophisticated way of understanding scattering which has proved very powerful in explaining particle interactions at high energies.

1962 e	Proposal of current algebra, a set of relations which set the scale for weak interactions of hadrons, clarified the weak interactions of hadrons with leptons and provided support for the quark hypothesis. Current algebra is also playing a role in estimating quark masses and other modern topics.
1963 a	Argonne Zero Gradient Synchrotron (ZGS) began operation with protons of 12.7 GeV. Accurate and systematic studies using advanced experimental techniques such as superconducting analyzing magnets and polarized targets, have been the forte of the ZGS program. Experiments in the 60's demonstrated the successes and limitations of Regge theory and confirmed duality (1968 a). More recently, the unique ZGS capability to accelerate polarized protons and deuterons (1973 a) has been exploited to study the spin dependence of proton and neutron interactions with complete spin information.
1963 b	Polarized proton target developed, allowing investigations of the spin dependence of the strong force. This type of target (with proton spins aligned) is widely used and is especially valuable at the ZGS, where experiments can now be done with both beam and target polarized (see 1973 a).
1964 a	Ω^- (omega) discovered at the AGS: a new hyperon with 3 units of strangeness which had been predicted by SU(3). The discovery of this particle completed the baryon decuplet and was a crucial confirmation of the theory.
1964 b	Quark hypothesis proposed: that the known hadrons (mesons and baryons) are composed of constituents called "quarks". At this stage, there were to be only 3 quarks, denoted by u, d and s. Mesons are made of a quark and an antiquark combination; baryons, of 3 quarks. During the 1970's, the quark hypothesis has been dramatically confirmed and extended to include two new kinds of quarks, the c and the b, and a sixth, the t, is predicted.
1964 c	CP violating $K_2^0 \to \pi^+\pi^-$ decays observed at the AGS, implying (by the CPT theorem) a violation of time reversal invariance and suggesting the possible existence of a new fundamental force.
1964 d	Charm hypothesis proposed: that there exists a fourth quark (c) with a new property called charm, a charge-like quantum number analogous to strangeness (such quantum numbers are now referred to by the generic term "flavors"). The basis for the charm hypothesis at this time was somewhat speculative; a stronger argument was offered in 1970. The existence of charmed quarks was demonstrated by the very exciting discoveries of 1974-76.

1965 a	Color hypothesis proposed: that each "flavor" of quark (e.g., u, d, s, c), comes in three tvpes or "colors". This distinction offered a way to place three identical fermions in an antisymmetric state inside a baryon in agreement with the Pauli exclusion principle which forbids such states. The color property is not interpreted as having a greater significance; the source of the strong force which binds the quarks into hadrons.
1965 b	First application of a superconducting magnet to bubble chambers, using the 10" helium-filled chamber at Argonne National Laboratory. The use of the superconductors in magnets is of great importance in modern high energy physics facilities including accelerators and polarized targets as well as bubble chambers.
1966	Stanford Linear Accelerator (SLAC) began operation with electrons of 20 GeV. Discoveries at SLAC include ep scaling, the tau lepton, parity violation in neutral currents and, via SPEAR (1972 b) much of the new physics of charmed quarks.
1967	Weinberg-Salam theory proposed by scientists from the US and abroad with the aim of unifving wht weak and electromagnetic interactions. The theory has since been strongly supported by theoretical and experimental developments. It may be comparable in importance to Maxwell's unification of electricity and magnetism in 1865, and points the way to a possible unification of all the forces.
1968 a	Duality: resonance formation and particle exchange models of hadron scattering were shown to be equivalent. This relationship has provided important insight into scattering processes.
1968 b	ep scaling observed at SLAC: large angle electron-proton scattering behaves like that expected if the proton contained free (non-interacting) pointlike constituents.
1969	Parton model proposed to explain ep scaling as due to constituents of the proton called "partons". Partons are now interpreted as being quarks and "gluons" (carriers of the strong force between quarks).
1970	12-foot bubble chamber began operation at the ZGS, using a large superconducting magnet. This was the first of the very large hydrogen bubble chambers and was used especially to study neutrino interactions.
1972 a	Fermi National Accelerator Laboratory (Fermilab) began operation with 200 GeV protons, reaching 400 GeV later in the year. This beam energy was considerably higher than that of any other accelerator. Major Fermilab discoveries include a wealth of information about neutrino and hadron interactions at very high energies, charm production, and the upsilon, made up of b quarks.

1972 b SPEAR began operation: an electron-positron colliding beam storage ring at SLAC with energies of 2.5 GeV in each beam, later raised to 4.1 GeV per beam. Charm was discovered and studied in great detail with this facility. SPEAR is the prototype of PEP at SLAC and PETRA at DESY, both higher energy e^+e^- colliding beam facilities.

1973 a ZGS accelerated polarized protons to 6 GeV (later increased to 12 GeV) a unique capability which allowed the study of the details of proton-proton scattering with both proton spins polarized.

1973 b Asymptotic freedom demonstrated as a property of Yang-Mills theories. This theoretical advance was important to the development of quantum chromodynamics (QCD), a gauge theory which treats the strong force that binds the quarks into hadrons as arising from the color "charge" of the quarks. The force decreases asympotically to zero as the momentum transferred in collisions increases without limit; thus the quarks behave as if they were free particles in very high energy collisions such as the ep scaling experiments (1968 b).

1974 a Ψ(psi)/J discovered: a new particle composed of a $c\bar{c}$ combination, i.e., a bound state of the predicted charmed quark (1964 d) and its antiquark. This dramatic discovery, which occurred independently at the AGS and at SPEAR, opened a new era in high energy physics. It put the quark model on a very solid foundation, confirmed the charm hypothesis, led to the discovery of a large family of charmed particles and encouraged a search for still other possible quarks, one of which has subsequently been found (the b; see 1977a). S. Ting and B. Richter shared the 1976 Nobel Prize for this revolutionary discovery.

1974 b Ψ' discovered at SPEAR: an excited state of $c\bar{c}$. This and many other excited states form a detailed energy spectrum of "charmonium" which provides a rigorous test of detailed theoretical predictions and strikingly confirms the quark hypothesis.

1975 a Λ_c (lambda) observed at the AGS and at Fermilab: a charmed baryon, i.e., a 3-quark combination with one of the quarks being the c. Finding particles like this with "naked" charm (as opposed to the hidden charm of the $c\bar{c}$ states) was a crucial confirmation of the quark model.

1975 b τ(tau) discovered at SPEAR: a new charged lepton, the first since the muon. The existence of this lepton and its associated neutrino provide a strong suggestion that there must also be another pair of quarks called the b and t, since quarks and leptons have so far occurred in matched pairs, e.g. (u, d) and (e, ν_e)

1975 c	Particle jets observed in e^+e^- collisions at SPEAR. Jets are clusters of particles moving in the same general direction; their existence is evidence for parton-parton collisions. The existence of jets has subsequently been confirmed in hadron collisions.
1976	D, D^* mesons discovered at SPEAR: charmed mesons, i.e., quark-antiquark combinations with one of the two being a c (or $\bar{c}$). These naked charm particles provided important support to the charm hypothesis and the quark model.
1977 a	Υ(upsilon) discovered at Fermilab: a new particle composed of $b\bar{b}$, where b is a fifth quark. The existence of this new quark had been suspected since the discovery of the τ lepton in 1975. Finding the b gives strong encouragement to search for its anticipated partner, the t quark.
1977 b	Υ' discovered at Fermilab: an excited state of the $b\bar{b}$ combination. This discovery provided important confirmation of the existence of the b quark and further tests of the quark theory.
1977 c	Strong spin dependence of proton-proton interaction discovered in ZGS experiments using polarized proton beam and target. At 1.5 GeV, protons with parallel spins interact far more strongly than protons with spins opposed. This effect, not yet fully understood, could be the first indication of a new kind of particle composed of six quarks.
1978	Parity violation in neutral currents observed in polarized electron-deuteron scattering at the SLAC linac. This observation of a very small scattering asymmetry provided one of the most striking confirmations of the Weinberg-Salam theory unifying the weak and electromagnetic interactions (1967).

REFERENCES

1945 E. M. McMillan, Phys. Rev. 68, 1943 (1945)
V. Veksler, J. Phys., USSR 9, 153 (1945)

1947 M. Conversi, E. Pancini and O. Piccioni, Phys. Rev. 71, 209 (1947)
E. Fermi, E. Teller and V. Weisskopf, Phys. Rev. 71, 314 (1947)
R. F. Marshak and H. A. Bethe, Phys. Rev. 72, 506 (1947)

1948 a G. Puppi, Nuovo Cimento 5, 505 (1948)
O. Klein, Nature 161, 897 (1948)
T. D. Lee, M. Rosenbluth and C. N. Yang, Phys. Rev. 75, 905 (1949)
B. Pontecorvo, Phys. Rev. 72, 246 (1947)

1948 b J. Schwinger, Phys. Rev. 73, 416 (1948)
H. A. Bethe, Phys. Rev. 72, 339 (1947)
J. B. French and V. Weisskopf, Phys. Rev. 75, 1240 (1949)
N. M. Kroll and W. E. Lamb, Phys. Rev. 75, 388 (1949)
Lamb Shift: W. E. Lamb and R. C. Retherford, Phys. Rev. 72, 241 (1947)

1949 b R. Bjorklund, W. E. Crandall, B. J. Moyer and H. F. York,
Phys. Rev. 77, 213 (1950)
A. G. Carlson, J. E. Hooper and D. T. King, Phil. Mag. 41, 701 (1950)

1949 c R. P. Feynman, Phys. Rev. 76, 749, 769 (1949);
Phys. Rev. 80, 440 (1950)

1951 J. L. Tuck and L. C. Teng, Phys. Rev. 81, 305 (1951)
K. J. LeCouteur and S. Lipton, Phil. Mag. 46, 1265 (1955)
A. V. Crewe and D. E. Kruse, Rev. Sci. Instrum. 27,5 (1956)

1952 a A. Pais, Phys. Rev. 100, 1487 (1955)

1952 b H. L. Anderson, E. Fermi, E. A. Long and D. E. Nagle, Phys. Rev. 85,
936 (1952)
K. A. Brueckner, Phys. Rev. 86, 106 (1952)
S. J. Lindenbaum and L. Yuan, Phys. Rev. 92, 1578 (1953), 93, 917 (195
F. de Hoffmann, N. Metropolis, E. F. Alei and H. A. Bethe,
Phys. Rev. 95, 1586 (1954)
J. Ashkin et al, Phys. Rev. 96, 1104 (1954)

1952 c E. Courant et al, Phys. Rev. 88, 1190 (1952)
N. C. Christofilos, US Patent No. 2,736,799 (filed 1950, issued 1956)

1953 a J. Schwinger, Phys. Rev. 91, 720, 723 (1953); 94, 1366 (1953)
W. Pauli, "Niels Bohr and the Development of Physics" (Pergamon,
London, 1955)
G. Lüders, Kgl. Danske Videnskab Selskab. Mat. Fys. Medd. 28.
No. 5 (1954)

1953 c	C. M. York, R. B. Leighton and E. K. Bjornerund, Phys. Rev. 90, 167 (1953)
1953 d	W. B. Fowler, R. P. Shutt, A. M. Thorndike and W. L. Whittemore, Phys. Rev. 91, 1287 (1953)
1953 e	M. Gell-Mann, Phys. Rev. 92, 833 (1953) T. Nakano and K. Nishijima, Progr. Theor. Physics 10, 581 (1953)
1954 b	E. W. Cowan, Phys. Rev. 94, 161 (1954)
1954 c	C. N. Yang and R. L. Mills, Phys. Rev. 96, 191 (1954)
1954 d	M. Gell-Mann, M. L. Goldberger and W. Thirring, Phys. Rev. 95, 1612 (1954) M. L. Goldberger, Phys. Rev. 99, 979 (1955) Experimental tests: K. J. Foley et al., Phys. Rev. Lett. 14, 862 (1965)
1955 a	O. Chamberlaih, E. Segre, C. Wiegand and T. Ypsilantis, Phys. Rev. 100, 947 (1955)
1955 b	M. Gell-Mann and A. Pais, Phys. Rev. 97, 1387 (1955)
1955 c	R. Hofstadter and R. W. McAllister, Phys. Rev. 98, 217 (1955) R. W. McAllister and R. Hofstadter, Phys. Rev. 102, 851 (1956)
1956 a	C. L. Cowan et al, Science 124, 103 (1956); Phys. Rev. 117, 159 (1960)
1956 b	T. D. Lee and C. N. Yang, Phys. Rev. 104, 254 (1956) Experimental confirmation: C. S. Wu et al, Phys. Rev. 105, 1413 (1957)
1956 c	K. Lande et al, Phys. Rev. 103. 1901 (1956)
1958 a	R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958) R. Marshak and E. Sudarshan, Phys. Rev. 109, 1860 (1958) N. Cabibbo, Phys. Rev. Lett. 10, 531 (1963)
1958 b	M. Goldhaber, L. Grodzins and A. W. Sunyar, Phys. Rev. 109, 1015, (1958)
1958 c	R. J. Van de Graaff, Proc. Accelerator Conference, High Voltage Engineering Corporation (1958) R. J. Van de Graaff, Nucl. Instr. Methods, 8, 195 (1960) M. E. Rickey and R. Smythe, Nucl. Instr. Methods, 18, 66 (1962) J. R. Richardson, J. Verba and B. T. Wright, Bull. Am. Phys. Soc. 7. 431 (1962) G. I. Budker, G. I. Dimov, Int. Conf. on High Energy Accelerators, Dubna, USSR, August 21-27 (1963). Published by the US Atomic Energy Commission's Division of Technical Information,-CONF-114, Book 2, pp. 1372-77.

1960 b M. Alston et al, Phys. Rev. Lett. 5, 520 (1960)

1960 c Y. Nambu, Phys. Rev. Lett. 4, 380 (1960)
Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122, 345 (1961)

1961 a M. Gell-Mann, Cal. Tech. Report CTSL-20 (1961), Phys. Rev. 125 1067 (1962)
Y. Ne'eman, Nucl. Phys. 26, 222 (1961)

1961 b A. Pevsner et al, Phys. Rev. Lett. 7, 421 (1961)

1961 c A. R. Erwin, R. March, W. D. Walker and E. West, Phys. Rev. Lett. 6, 628 (1961)

1961 d B. C. Maglic, L. W. Alvarez, A. H. Rosenfeld and M. L. Stevenson, Phys. Rev. Lett. 7, (1961); A. Pevsner et al, Phys. Rev. Lett. 7, 421 (1961)

1961 e M. Alston et al, Phys. Rev. Lett. 6, 300 (1961)

1961 f T. L. Collins, "Long Straight Sections for AG Synchrotrons", Cambridge Accelerator Report CEA-86, July 10, 1961 (unpublished)
W. K. Robinson and G. A. Voss, "Possible Use of the CEA Directly as a Colliding Beam Facility", Cambridge Electron Accelerator Internal Report CEAL-TM-149, October 22, 1965 (unpublished)

1962 a G. Danby et al, Phys. Rev. Lett. 9, (1962)

1962 b S. J. Lindenbaum et al, Nucl. Instr. Methods 20, 297 (1963); 30, 45 (1964)

1962 c L. Bertanza et al, Phys. Rev. Lett. 9, 180 (1962)

1962 d T. Regge, Nuovo Cimento 14, 951 (1959)
G. Chew, S. Frautschi and S. Mandelstam, Phys. Rev. 126, 1202 (1962)
G. Chew and S. Frautschi, Phys. Rev. Lett. 7, 394 (1961); 8.41 (1962)

1962 e M. Gell-Mann, Phys. Rev. 125, 1067 (1962)
M. Gell-Mann, Physics 1, 63 (1964)

1963 b O. S. Leifson and C. D. Jeffries, Phys. Rev. 122, 1781 (1961)
O. Chamberlain et al, Bull. Am. Phys. Soc. 8, 38 (1963)

1964 a V. E. Barnes et al, Phys. Rev. Lett. 12, 204 (1964)

1964 b M. Gell-Mann, Phys. Lett. 8, 214 (1964)
G. Zweig, CERN Report 8419/TH 412 (1964)

1964 c J. H. Christenson et al, Phys. Rev. Lett. 13, 138 (1964)

1964 d J. D. Bjorken and S. L. Glashow, Phys. Lett. 11, 190 (1964)
S. L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D2, 1285 (1970)

1965 a M. Han and Y. Nambu, Phys. Rev. 139B, 1006 (1965)
O. W. Greenberg, Phys. Rev. Lett. 13, 598 (1964)

1965 b M. Derrick et al, Proc 1966 Int. Conf. Instrumentation for High Energy Physics (Stanford), p.264 (1966)

1967 S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967)
A. Salam, "Elementary Particle Physics: Relativistic Groups and Analyticity" (Nobel Symposium No. 8), Svartholm, Ed., Stockholm, Almquist and Wiksell (1968)

1968 a R. Dolen, D. Horn and C. Schmid, Phys. Rev. 166, 1768 (1968)

1968 b E. D. Bloom et al, Phys. Rev. Lett. 23, 930.935 (1969); Phys. Rev. D 5, 528 (1972)

1969 R. P. Feynman, Phys. Rev. Lett. 23, 1415 (1969); "Photon-Hadron Interactions", Benjamin (1972)
J. D. Bjorken and E. A. Paschos, Phys. Rev. 185, 1975 (1969)

1973 b D. Politzer, Phys. Rev. Lett. 30, 1346 (1973)
D. Gross and F. Wilczek, Phys. Rev. Lett. 30, 1343 (1973)

1974 a J. J. Aubert et al, Phys. Rev. Lett. 33, 1404 (1974)
J. E. Augustin et al, Phys. Rev. Lett. 33, 1406 (1974)

1974 b G. S. Abrams et al, Phys. Rev. Lett. 33, 1453 (1974)

1975 a E. Cazzoli, et al, Phys. Rev. Lett. 34, 1125 (1975)
B. Knapp, et al, Phys. Rev. Lett. 37, 882 (1976)
A. M. Cnops, et al. 42, 197 (1979)

1975 b M. L. Perl et al, Phys. Rev. Lett. 35, 1489 (1975)
M. L. Perl et al, Phys. Lett. 70B, 487 (1977)

1975 c G. Hanson et al, Phys. Rev. Lett. 35, 1609 (1975)

1976 G. Goldhaber et al, Phys. Rev. Lett. 37, 255 (1976)
J. Peruzzi et al, Phys. Rev. Lett. 37, 569 (1976)

1977 a	S. W. Herb et al, Phys. Rev. Lett. 39, 252 (1977)
1977 b	W. R. Innes et al, Phys. Rev. Lett. 39, 1240 (1977)
1977 c	I. P. Auer et al, Phys. Lett. 70B, 475 (1977) K. Hidaka et al, Phys. Lett. 70B, 479 (1977)
1978	C. Y. Prescott et al, Phys. Lett. 77B, 347 (1978)

U.S. Major Accomplishments in High Energy Physics Since 1945

Addendum to June 1979 Edition

1979-82 - Particle Physics connection with cosmology expanding. Early moments in the evolution of the universe are controlled by ultra-high energy particle interactions. The observed preponderance of matter over antimatter in the universe has been related to the unification of weak, strong, and electromagnetic forces and to the phenomenon of CP violation. New cosmological models for the universe have been proposed to explain the origin of large scale effects in the universe as seen today.

S. Weinberg, Phys. Rev. Lett. 42, 850 (1979)
D. Toussaint et al., Phys. Rev. Lett. D19, 1036 (1979)
A. H. Guth and S. H. H. Tye, Phys. Rev. Lett. 44, 631 (1980)
A. H. Guth, Phys. Rev. Lett. 23, 347 (1981)
A. Albrecht and P.J. Steinhardt, Phys. Rev. Lett. 48, 1220 (1982)

1979 - First evidence for gluon jets at DESY/PETRA (with participation of U.S. groups). The standard model of elementary particles that emerged after the discovery and interpretation of the J/ψ particle asserted that all observed strongly interacting particles were made of charged particles called quarks held together by particles called gluons. Although all strong interactions were attributed to gluons, there had been no direct, active evidence for their existence until these experiments, which observed jets of particles associated with high-momentum gluons produced in electron-positron collisions.

S. L. Wu et al., Z. Phys. C 2, 107 (1979)
R. Brandelik et al., Phys. Lett. 86B, 243 (1979)
D. Barber et al., Phys. Rev. Lett. 43, 830 (1979)

1980 - Discovery of the charmed counterpart of the eta particle, called eta-c, at a mass of 2.98 GeV at SLAC/SPEAR. When the J/ψ particle was discovered, it was hypothesized to be made of a new kind of particle, called a charmed quark, which was heavier than the known quarks, but had identical strong interactions. The hypothesis required that there be a whole new spectrum of particles, including one, the eta-c, lighter than the J/ψ . Its discovery, at the expected mass, was an important confirmation of the existence and properties of charmed quarks.

T. M. Himel et al., Phys. Rev. Lett. 45, 1146 (1980)
R. Partridge et al., Phys. Rev. Lett. 45, 1150 (1980)

1980-82 - Monte Carlo methods in Lattice QCD yield hadron mass estimates from first principles. Quantum chromodynamics (QCD) had become recognized as a viable candidate for a theory of strong interactions because of its successes in describing some very high energy processes. The Monte Carlo calculations were the first direct, if approximate, application of the fundamental theory to that most basic of strong interaction phenomena, the spectrum of particles and resonances. This work is influencing condensed matter physics and is having important consequences for advanced computer design.

M. Creutz, Phys. Rev. Lett. 45, 313 (1980)
D. Weingarten, Phys. Lett. 109B, 57 (1982)
J. Kogut et al., Phys Rev. Lett. 48, 1140 (1982)

1981-84 - Precision measurement of the anomalous magnetic moment of the electron; calculation of the eighth order quantum electrodynamic contribution to the magnetic moment. The anomalous magnetic moment of the electron and its gyromagnetic ratio can both be measured and calculated to extraordinarily high precision, and they permit the most careful comparison of theory with experiment of any physical system. The agreement of theory and experiment is now known to be correct to within a few parts in a trillion for the magnetic moment.

A. Dehmelt et al., Phys. Rev. Lett. 47, 1679 (1981)
T. Kinoshita, Phys. Rev. Lett. 47, 1573 (1981); 52, 717 (1984)

1982 - Electro-weak interference observed in electron-positron collisions at DESY/PETRA (with U. S. teams participating) and SLAC/PEP. This discovery confirms energy-dependent predictions of the unified theory of weak and electromagnetic interactions up to the highest energies available.

B. Adera et al., Phys. Rev. Lett. 48, 1701 (1982)
R. Brandelik et al., Phys. Lett. 110B, 173 (1982)
W. Bartel et al., Phys. Lett. 108B, 140 (1982)

1983 - Discovery of the W, the charged carrier of weak interactions, and the Z, the neutral carrier, at CERN (with participation of U.S. groups). Since the 1950's, there have been attempts to unify the weak and electromagnetic interactions. By the beginning of the 1970's, the very attractive Glashow-Weinberg-Salam theory was formulated, and it enjoyed many successes. Its most definitive prediction was the existence of the W and Z particles. Their discovery is powerful evidence for this theoretical understanding of unified weak and electromagnetic interactions.

G. Arnison et al., Phys. Lett. 122B, 103 (1983); 126B, 398 (1983)

1983 - Discovery of new stable meson with fifth-quark (b-quark) quantum number at Cornell/CESR. This discovery confirms expectations that such particles should exist based on previous discovery of the Upsilon particle at Fermilab in 1977.

S. Behrends et al., Phys. Rev. Lett. 50, 881 (1983)

1983 - Proton decay experiments have succeeded in raising the lower limits on the proton decay lifetime to $\geq 10^{32}$ years. On this basis, the simplest model of grand unification of weak, strong, and electromagnetic forces has been excluded and new theoretical work is proceeding to incorporate the proton decay experimental limits. Before grand unification ideas emerged, theories allowed only for the possibility that the proton (the nucleus of the hydrogen atom) was absolutely stable.

R. Bionta et al., Phys. Rev. Lett. 51, 27 (1983)

1983 - World's first superconducting proton synchrotron at Fermilab accelerated protons to 512 GeV, a world's record, and subsequently to 800 GeV in 1984. This achievement results from an extensive U.S. R&D effort on superconducting magnets and is a forerunner of worldwide use of this technology. A vital component has been the development, construction, and operation of the world's largest helium refrigerator.

1983 - Longer than expected lifetime for B-meson measured at SLAC/PEP which constrains parameters for CP violation and the top-quark mass. This measurement utilizes new high precision experimental techniques to measure directly very short particle lifetimes.

E. Fernandez et al., Phys. Rev. Lett. 51, 1022 (1983)
N. Lockyer et al., Phys. Rev. Lett. 51, 1316, (1983)
D. Klem et al., Phys. Rev. Lett. 53, 1873 (1984)

1983-84 Nuclear dependence of nucleon internal structure seen in lepton beam experiments. These experiments establish that quarks within nucleons in nuclear matter behave differently than quarks in free protons and neutrons.

J. Aubert et al., Phys. Lett. 123B 275 (1983)
A. Bodek et al., Phys. Rev. Lett. 50, 1431 (1983)
R. Arnold et al., Phys. Rev. Lett. 52, 727 (1984)

1984 - For many years there have been several inconsistent experimental results, obtained from various difficult experiments worldwide, on the beta decay of the Sigma Minus hyperon. The latest results from Fermilab are considered to resolve these inconsistencies and to be definitive verification of the Cabbibo theory of beta decay.

S. Y. Hsueh et al., Phys. Rev. Lett. (1985)

1984 - Brookhaven National Laboratory accelerated polarized protons at the AGS to the highest energy yet attained-16 GeV. First experiments studied the elastic scattering of unpolarized protons on a polarized target. This scattering was found to depend very strongly on the spin alignment. How these results depend on the quark structure of protons is yet to be determined.

1984 - Observation at Cornell/CESR of the F meson, carrying both charmed and strange quarks, at 1970 MeV mass. This elusive particle was predicted to exist at about this mass by dynamical theories of heavy charmed quarks.

1984 - Development of superstring theories that promise unification of all forces including gravity. The goal of finding a unified description of all the fundamental interactions in nature has been a powerful theme in elementary particle physics. Superstring theories, although their development is just in its infancy, have the possibility for the first time of providing such an "ultimate theory of everything."

M. B. Green and J. H. Schwarz, Phys. Lett. 149B, 117 (1984).

1984 - Radio Frequency Quadrupole (RFQ) linac first used in Brookhaven National Laboratory. This table-top-size facility accelerates polarized particles to 750 kilovolts for injection into the 200 MeV linac which in turn serves as an injector for the 30 GeV Alternating Gradient Synchrotron. The RFQ serves the function of the very large and relatively unreliable Cockcroft-Walton electrostatic pre-injector and marks the beginning of a world-wide conversion to RFQ's.

PROGRAM ACCOMPLISHMENTS AT THE NUCLEAR PHYSICS ACCELERATOR FACILITIES[1]

ATLAS
Argonne National Laboratory
Argonne, Illinois

Scientists at Argonne have been instrumental in identifying the contributions of second-order collective excitations to the single-particle states made in transfer reactions. They have been leaders in the effort to understand the limits governing the fusion of two complex nuclei at intermediate energies. The dependence of incomplete fusion on projectile type and on mass asymmetry in the entrance channel have been established. They have contributed heavily to the investigation of resonance phenomena in di-nucleon quasi-molecular formation. Of special interest has been the work on collective states which investigates the way that nuclei deform, sometimes prolate and sometimes oblate, under the addition of large amounts of angular momentum. The prominence of quasi-elastic reaction channels and its influence on other reaction channels has been established for very heavy collision systems.

TANDEM/AGS HEAVY ION FACILITY
Brookhaven National Laboratory
Upton, New York

Pioneering studies of heavy ion induced direct reactions encompassing inelastic scattering and particle transfer have led to a quantitative theory for the reaction mechanism. The gamma-ray spectroscopy of very high spin states in many new isotopes has led to a better understanding of how collective nuclear behavior changes over to independent particle behavior as higher spins and excitations are reached. The complex structure of back angle elastic scattering of heavy ions has been extensively studied at Brookhaven. High energy resolution studies of heavy ion radiative capture unexpectedly demonstrated that giant resonances, both quadrupole and dipole, could be built on highly excited nuclear states.

---

[1] This material was excerpted from DOE's publication entitled Nuclear Physics Accelerator Facilities, January 1985.

CYCLOGRAAFF ACCELERATOR
Triangle Universities Nuclear Laboratory
Duke University
Durham, North Carolina

TUNL measurements of the fine structure of analog states and of amplitude correlations are unique. These are the only charged-particle data of sufficient quality to test new statistical theories and provide valuable information to complement neutron studies. These measurements have provided protron strength functions obtained from individual resonances. The charged-particle program has recently used polarized deuteron beams to initiate reactions which probe the nonspherical nature of the wave function for ^{4}He. On the tandem accelerator, an efficient three-stage bunching system has been constructed which facilitates measurements with pulsed, polarized beams. Up to 80 percent of the DC beam can be obtained in pulses on target with 2 ns burst width. A major achievement of the capture program in the past few years has been the production of high quality, polarized fast-neutron data, using this pulsing system, from which the collective E2 strength in the capture reaction can be deduced. In addition, Cyclograaff beams have been used to study the nature and properties of giant resonances built on highly excited states. The neutron program has provided neutron polarization information for the characterization of the spin-orbit interaction of neutrons with nuclei ranging from ^{1}H to ^{208}Pb. As a result, improved neutron-nucleus optical models have been developed to describe cross-section and polarization data over the 8-40 MeV range.

During the existence of this laboratory, 131 graduate students have earned Ph.D. degrees in experimental nuclear science. A large fraction of these are now in academic institutions and national laboratories. At present, some 29 graduate students are in residence at TUNL and working towards the Ph.D. degree.

SUPERHILAC/BEVALAC
Lawrence Berkeley Laboratory
Berkeley, California

The Bevalac scientific program has been able to delve deeply into new regions of nuclear equations of state by making high-temperature compressed matter. Measurements have been made of the size of "hot spots" created when heavy nuclei collide. In addition, studies of nuclear collisions in which all (100 or more) secondary charged particles are characterized have revealed the phenomena of collective energy flow--a phenomena in which high pressures deflect many particles away from the beam direction. Other studies of central collisions of relativistic heavy ions have uncovered a puzzle in the production of mesons. Pions are produced several times less abundantly than predicted, but kaons are produced several times more copiously than expected.

The SuperHILAC has long been a world center for research with very heavy ion beams. The pioneering program in deep-inelastic scattering studies continues with a new generation of particle and gamma-ray detectors and coincidence experiments, and the relationship between the evaporation of particles and fission is also being explored. Electromagnetic moment measurements via Coulomb excitation and Doppler-shift techniques are providing stringent tests of today's nuclear models. Heavy-element isotopes and nuclei near the proton drip line are being studied with new isotope separators.

88-INCH CYCLOTRON
Lawrence Berkeley Laboratory
Berkeley, California

Recent research accomplishments include: (1) observation of a new radioactive decay mode--beta-delayed two proton emission from the exotic nuclei ^{22}Al and ^{26}P; (2) discovery of a giant dipole resonance built on highly deformed, high angular momentum states; (3) observation of nuclei with moments of inertia approaching the rigid-body value; (4) studies of the emission of heavy, complex fragments by highly excited nuclei; (5) the separation of transfer and breakup processes in heavy ion reactions utilizing a very large solid angle plastic scintillator array; and (6) studies of the properties of the transfermium nuclei produced by heavy ion beams and a highly radioactive target of einsteinium.

CLINTON P. ANDERSON MESON PHYSICS FACILITY (LAMPF)
Los Alamos National Laboratory
Los Alamos, New Mexico

Recent research accomplishments at LAMPF include: (1) use of the pion charge exchange reactions to excite isotopic analog states, i.e., states of the nucleus showing strong symmetry between neutrons and protons; (2) discovery of an isotopic monopole giant resonance (i.e., neutron-proton breathing mode oscillation); (3) first observation of free muonium; (4) observation of the Lamb shift in muonium; (5) a stringent new limit on the rare decay, muon decaying to 3 electrons, namely 1×10^{-10}; (6) an experimental demonstration of the need for using the full Dirac wave function to describe polarized nucleon-nucleus scattering; and (7) evidence found with the pion double-charge-exchange reaction on ^{14}C at 50 MeV which showed that a six-quark cluster component is required in the nuclear wave function.

BATES LINEAR ACCELERATOR CENTER
Massachusetts Institute of Technology
Middleton, Massachusetts

Recent research achievements include: (1) stringent tests of nuclear mean field theories by precision measurements of electromagnetic structure near closed shells and by the systematic study of nuclear stretched states (elementary excitations resulting from the maximum possible angular momentum transfer in a one-step process); (2) demonstration of the importance of meson exchange currents in the nucleus, particularly in the short distance structure of nuclear magnetization; (3) measurements of the nuclear response functions at large energy transfer resulting in total strengths unexplainable in the conventional framework of static nucleons; (4) measurement of the nuclear interaction of the lowest nucleon excited state (the delta) by means of coherent photoproduction of neutral pions, photon scattering, and deep-inelastic electron scattering; (5) studies of the mechanism for pion production in nuclei; and (6) (e,e'p) coincidence studies of proton knockout which demonstrate the importance of multinucleon contributions to the electromagnetic current.

HOLIFIELD HEAVY ION RESEARCH FACILITY
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Changes in nuclear shapes, the role of rotational alignments, and the crossing of bands have been established through studies of discrete high-spin states and states in the continuum that are populated in both compound nuclear and transfer reactions. Lifetimes measured for the discrete states are especially important in determining their character. Isomer shifts and quadrupole and magnetic moments have been determined for the ground and isomeric states of short-lived Tl nuclei from the hyperfine structure resulting from laser-induced optical pumping. Gamma-ray decay branches have been measured from the giant quadrupole resonance in ^{208}Pb and provide, for the first time, microscopic composition of the resonance. The sharing of excitation energy among fragments has been explored under varying conditions between the two extremes of equal energy and of temperature equilibration. Evidence for a localized hot source in the nucleus has been established from small angle p-p correlations and from spectra of energetic protons and neutrons emitted in heavy ion induced reactions. The decrease of fusion cross section and corresponding increase in incomplete fusion channels have been studied as a function of energy and correlated with the impact parameter and entry channel. Lifetimes of reaction processes around 10^{-18} seconds have been measured through blocking of emitted particles by crystal lattices. Observation of neutral pi mesons at projectile energies of 25 MeV/AMU (the lowest energy to date for production of pions) has established the importance of cooperative action of many nucleons.

TEXAS A&M CYCLOTRON
Cyclotron Institute
Texas A&M University
College Station, Texas

Texas A&M scientists have conducted an extensive series of high precision studies of giant resonance states in nuclei. From these experiments, giant monopole resonances (the entire nucleus contracts and expands as a unit) and their possible splitting have been identified and measured providing new and unique information about nuclear compressability. In a systemmatic study of nuclear stability, the masses of nuclei near the limits of particle stability have been determined and the need for a charge-dependent nuclear force demonstrated. Experimenters at Texas A&M have demonstrated that "massive transfer" (a large part of the projectile transfers to the target) occurs quite generally in heavy ion reactions and populates nuclear states within a narrow angular momentum window, providing a new tool for nuclear spectroscopy. Studies of x-ray emission in heavy ion collisions have demonstrated the importance of fast electron rearrangement in highly ionized atoms and have led to the discovery of a resonant electron transfer process in ionic solids. The protocol for treatment of human cancer with neutron therapy was established in a program which treated over 500 patients in an 8-year period. Texas A&M scientists were the first to obtain quantitative determination of oxygen and boron at the 10^{-11} grams per gram of sample and 10^{-13} grams per gram of sample levels, respectively, using charged particle activation analysis and the first to profile gold by means of heavy ion backscattering. The Cyclotron Institute has been a significant source of scientific manpower with 45 students receiving Ph.D. degrees and 23 receiving M.S. degrees from cyclotron-based research from 1970 to 1984. Fifty-four scientists received their postdoctoral training during the same period.

TANDEM/SUPERCONDUCTING BOOSTER ACCELERATOR
Nuclear Physics Laboratory
University of Washington
Seattle, Washington

Recent difficult and innovative experiments include studies of the weak nucleon-nucleon and electron-nucleon force by nuclear and atomic parity mixing, of nucleon charge conservation, and of the breakdown of isospin symmetry in nuclei. High precision investigations of deviations from Rutherford scattering in sub-Coulomb heavy ion scattering have permitted the observation of the dynamic effects of relativistically invariant wave equations as well as the effects of electron screening and dynamic nuclear polarization. Other examples of recent research include the study of the effect on atomic ionization of "time delay" in nuclear reactions, evidence which indicates the absence of the "low 1-value window" predicted in heavy ion fusion reactions, and the demonstration that back-angle analyzing powers observed in the inelastic scattering of polarized protons to the continuum arise from orbiting.

TANDEM VAN DE GRAAFF ACCELERATOR
A.W. Wright Nuclear Structure Laboratory
Yale University
New Haven, Connecticut

Recently, the laboratory reported: experimental evidence for the first supersymmetry observed in nature centering on ^{193}Ir; an entirely new form of dipole nuclear collectivity; a spectrum generating algebraic approach to the understanding of nuclear molecular interactions; nuclear astrophysical cross sections pertinent to the formation of the solar system; and emission of monoenergetic positrons in supercritical Coulomb fields.

In applied areas, fundamental new information on the physics of the sputtering process induced by both keV and MeV beams has been reported as well as new techniques for beam induced adhesion of thin films, contacts, and the like, of importance in microelectronics. The quantitative, nondestructive characterization of hydrogen in solids that was reported several years ago has been further refined for use in many areas of technology including fusion energy research.

For more than 20 years, Yale has graduated more Ph.D.'s in experimental nuclear physics than any other institution in the world. Currently, 31 graduate students are working in the Wright Laboratory.

SOME MAJOR U.S. ACCOMPLISHMENTS IN NUCLEAR PHYSICS SINCE 1945

Prepared by:

Division of Nuclear Physics
U.S. Department of Energy
Washington, D.C. 20545
March 15, 1985

SOME MAJOR U.S. ACCOMPLISHMENTS IN NUCLEAR PHYSICS SINCE 1945

1945-1949

Nuclear shell model successfully describes systematics of low lying nuclear states in spherical nuclei throughout the periodic table. In this picture nucleon interactions within a nucleus are assumed to depend mainly on an average potential generated by all the other nucleons. Inclusion of a spin-orbit component in the potential made this model reproduce the order of the single particle levels in the nucleus. Other spectroscopic data such as binding energies of closed shell nuclei and spins of nuclei find a unified explanation in this model.

Pion is discovered in cosmic rays and identified as the particle postulated by Yukawa as the carrier of the strong force. The long range part of the nuclear force is still theoretically described in terms of the exchange of pions.

1950-1959

Nuclear optical model sucessfully represents nuclear scattering as a wave moving through a complex potential. Along with its generalizations, the distorted wave Born approximation and the coupled channels Born approximation, it forms the basis for quantitative experimental studies of nuclear properties such as size, shape, and excited state configurations.

Collective model of the nucleus is developed to describe nuclear excitations involving rotation and vibration. The idea that some nuclei could be intrinsically deformed in their ground state gave the conceptual basis for understanding their low lying excitations.

Electron scattering program on nuclei at Stanford and at other electron accelerators provide precision measurements of nuclear sizes and shapes (charge and current distributions) for nuclei throughout the periodic table.

Discovery of the neutrino confirms the existence of the massless, uncharged particle that was postulated in 1933 in order to understand the observed properties of nuclear beta decay.

Prediction of parity non-conservation confirmed in the detected angular distribution of beta decay electrons from a polarized Cobalt-60 nucleus. This result showed that the laws of physics need not be invariant under space reflection.

Helicity of the neutrino is determined by the detection of the nuclear gamma decay of Samarium-152 subsequent to its production in beta decay from Europium-152. This determination of the "left-handed" nature of the neutrino was very important in the understanding of the weak force.

Nuclear astrophysics provided the understanding of the basic mechanism of the evolution of the structure of the elements of the universe. Detailed development of the scheme of nuclear synthesis in stars continues.

Nuclear many body theory achieved crucial technical breakthroughs to allow it to treat the strongly interacting nucleons in a theory of nuclear matter. Three decades later the difficulties of this field have been sufficiently overcome to allow the seperation of two-body and three-body effects.

1960-1969

Nuclear reaction theory develops on a number of fronts to the point where it can be used to obtain spectroscopic information from direct nuclear reactions such as inelastic scattering and nucleon transfer.

Isobaric analog states are discovered. Sharp nuclear resonances seen in proton reactions correspond to a new type of nuclear state which is identical to a neighboring nucleus state except that a neutron is replaced by a proton.

New elements and new isotopes are discovered in ongoing nuclear science programs at a number of laboratories.

User accelerator facilities are developed. A new generation of large nuclear physics accelerators are developed, including sector focused cyclotrons, proton and electron linacs, and heavy ion tandems. These shared facilities set the stage for the nuclear physics discoveries of the 1970's and 1980's.

Shell effects in deformed nuclei were worked out in a theoretical model to understand deformed nuclei in terms both of a liquid drop and shell model corrections. This model led to the prediction of isomeric states decaying by spontaneous fission and to a quantitative description of the fission process.

1970-1979

Discovery of the giant quadrupole resonance began a new effort to study the fundamental vibrations that can be excited in the nucleus as a whole. Subsequent studies of giant resonances included the first measurements of nuclear compressibility.

Intermediate energy nuclear physics became a dominant subfield with the opening of the Los Alamos Meson Facility which provided intense high energy proton beams and secondary beams of pion, muons, and neutrinos. The role of the pion within the nucleus has been elucidated.

Interacting boson model is developed to provide a unification of different types of nuclear collective excitations (rotation, vibaration, and symmetric behavior that falls between these two extremes).

Transuranic elements up to element 106 are discovered at Berkeley by irradiating heavy targets with heavy ions. Discovery of tranuranic elements continues a program which has been active for decades.

Solar neutrino experiment challenged the understanding of the nature of the neutrino and of solar models. The unexpectedly small number of neutrinos observed is still not completely understood.

Deep inelastic scattering of heavy ions is observed. Study of this process, in which two heavy nuclei collide violently but do not fuse, has been important in the development of an understanding of nuclear mass and energy transfer mechanisms.

1980-1984

Role of quark substructure of nucleons on nuclear properties is measured at SLAC. Electron scattering gives results complementary to the European Muon Collaboration (EMC) result, namely that the quark structure of nucleons in nuclei differs significantly from that in free nucleons.

Sub-threshold pion production observed in heavy ion reactions demonstrates a surprising collectivity in the energy taken from the nucleons to produce the pions.

Quark-gluon plasma is predicted. Based on the current quantum chromodynamic (QCD) theory of the strong interaction, it was predicted that in a modest nuclear volume (e.g. order of a hundred nucleons) at very high densities and temperatures, it should be possible to effectively dissolve the underlying nucleon substructure of nuclei and create a plasma of the quark and gluon constituents of nucleons.

Giant Gamow-Teller strength in nuclei is measured using the (p,n) reaction. The amount of strength seen suggests the necessary role of the delta particle in nuclear structure.

Electron type neutrino elastic scattering from electrons is observed at the Los Alamos Meson Facility. This development provides a new capability for sensitive tests of electroweak theories.

Accelerator technology advances physics capabilities at a number of laboratories: the Bevelac accelerates uranium to relativistic energies; the Argonne ATLAS superconducting accelerating cavities become operational; LAMPF achieves beams of 1.2 mA, 20% above design current.

Nuclear liquid flow is observed in relativistic heavy ion experiments.

DEPARTMENT OF ENERGY

FISCAL YEAR 1986 CONGRESSIONAL BUDGET REQUEST

ENERGY SUPPLY RESEARCH AND DEVELOPMENT

VOLUME 3

SUPPORTING RESEARCH AND TECHNICAL ANALYSIS

TABLE OF CONTENTS

Program Overview 137
Basic Energy Sciences 139
Energy Research Analysis 201
University Research Support 207
University Research Instrumentation 215
Advisory and Oversight Program Direction 217
Multiprogram General Purpose Facilities 221

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
PROGRAM OVERVIEW

SUPPORTING RESEARCH AND TECHNICAL ANALYSIS

Developing new and improving the use of current energy sources continues to be of fundamental importance to the general health and welfare of the nation and its economy. The role of supporting research and technical analysis is to expand the scientific and engineering knowledge base on which the Nation's future energy options depend and to provide independent, objective analyses and assessments of research and technical needs relating to energy. The applied technology efforts of industry and government need this broad knowledge base to devise new concepts, develop new materials, and devise new and improved processes and techniques for energy production, conversion and utilization. We must continue to strengthen our understanding of the scientific basis of energy-related phenomena to overcome limitations on productivity growth, erosion of the country's competitive position with foreign nations and additional pressure on the United States balance of trade.

Eight programs comprise the Office of Energy Research's portion of the Supporting Research and Technical Analysis category of the agency's budget: (1) Basic Energy Sciences (BES); (2) Energy Research Analysis (ERA); (3) Advisory and Oversight Program Direction; (4) University Research Support (URS); (5) University Research Instrumentation (URI); (6) Multiprogram Laboratories Facilities Support (MLFS); and (7) Policy and Management.

The Nation's future energy options depend directly on our available fundamental scientific and engineering knowledge base. The mission of the Basic Energy Sciences (BES) program is to carry out long range, basic research activities needed to enhance this base. The major product of the BES program continues to be increased knowledge which becomes a part of the body of data on which applied technologies rest. In addition to a major focus on disciplinary research, there is also emphasis on innovative applications of new knowledge to energy problems, and on the early application of the results.

The Energy Research Analysis (ERA) program provides the capability for independent, rigorous assessment of the base of research that underlies a variety of energy technologies. Assessments are consolidated under one organization, the Office of Energy Research, in fulfillment of legislated responsibility for the Director to advise the Secretary on the agency's research and development programs.

The University Research Support (URS) program consists of two major subprograms and a set of program activities focused on the following three primary objectives: (1) to strengthen university capability to do energy research; (2) to strengthen the quality and increase the number of students interested in pursuing energy-related professional careers; and (3) to enhance technology transfer activities through cooperative research efforts between universities, the agency's national laboratories and private industry. The first subprogram, University/National Laboratory Cooperative Research, is directed at strengthening the capabilities of both universities and national laboratories as major energy research performers in the conduct of long range energy research. Many of the activities supported within this subprogram involve joint efforts between university and laboratory-based researchers. The second subprogram, Energy Manpower Development, includes efforts to increase the number of students pursuing energy-related engineering and science careers. This subprogram also includes the Department's statutory responsibility for assessing the supply and demand of manpower for both current and projected energy R&D programs.

The University Research Instrumentation (URI) program provides grants to major research universities to purchase state-of-the-art, scientific instrumentation used in energy-related research areas such as combustion, biological research, catalysis, and engineering research.

The goal of the Multiprogram Laboratories Facilities Support (MLFS) program is to provide for the rehabilitation, upgrade, and replacement of general purpose support facilities which are essential to the continued operations of the agency's multiprogram laboratories. The program consists of two major subprograms; Multiprogram General Purpose Facilities (MGPF) and Environmental Compliance (Oak Ridge National Laboratory (ORNL)).

Multiprogram General Purpose Facilities are "facilities" which are suited to many different users and programs; they include roads, railroads, site utilities, and support buildings such as laboratories, office buildings, shops, warehouses, etc. They are restricted to facilities where no one program uses more than 60 percent of the facility. The replacement cost of the existing general purpose facilities at the multiprogram laboratories exceeds $6,500,000,000. The MGPF program is required to maintain this investment and to ensure its viability. The program will be required as long as the multiprogram laboratory facilities are utilized to perform research and development functions for the Department. The program is an appropriate Federal role reflecting the responsible management of the Government's real property. The program is based on the premise that through continuous usage and aging, facilities deteriorate over time to a point where they are no longer useful to perform their intended functions and must be rehabilitated or replaced.

The Environmental Compliance (ORNL) subprogram provides for an extensive environmental cleanup effort at the Oak Ridge National Laboratory. This program would allow initiation of activities to correct environmental problems in the following categories: process waste systems upgrades, hazardous and toxic material management, watershed discharge improvements, spill site characterization and cleanup, and upgrades of sanitary and storm sewers.

Advisory and Oversight Program Direction provides funds for the personnel resources required by the Director of Energy Research to carry out his responsibilities specifically assigned by legislation (P.L. 95-91), as well as those mandated by the Secretary of the Department of Energy, in areas beyond the scope of the Office of Energy Research programs. This staff has the responsibility to advise the Secretary with respect to the well-being and management of the multiprogram laboratories; to administer the Department's R&D Laboratory Technology Transfer Program; to supervise or support research activities carried out by any of the Assistant Secretaries; to provide for institutional planning by the Multiprogram Laboratories; and to provide for program management of the Energy Research Analysis, University Research Support and Multiprogram General Purpose Facilities programs. The program provides funds only for the salaries and related personnel expenses for the personnel who carry out the studies, analyses, monitoring and coordination activities required to support the Director and the Secretary.

The Office of Energy Research Policy and Management program provides for the salaries and related expenses associated with staff in the immediate office of the Director, of Energy Research.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
BASIC ENERGY SCIENCES
ENERGY SUPPLY RESEARCH AND DEVELOPMENT
(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
Basic Energy Sciences				
Materials Sciences				
Operating Expenses.......	$124,560	$133,055	$133,055	$138,496
Capital Equipment........	12,780	15,450	15,450	15,450
Construction.............	16,440	43,620	43,620	28,995
Subtotal................	153,780	192,125	192,125	182,941
Chemical Sciences				
Operating Expenses.......	75,165	79,495	79,495	79,495
Capital Equipment........	6,520	8,840	8,840	8,840
Construction.............	450	6,050	6,050	5,830
Subtotal................	82,135	94,385	94,385	94,165
Nuclear Sciences				
Operating Expenses.......	37,733	40,350	40,350	43,338
Capital Equipment........	2,150	2,950	2,950	2,754
Construction.............	270	300	300	1,300
Subtotal................	40,153	43,600	43,600	47,392
Applied Mathematical Sciences				
Operating Expenses.......	14,605	35,074	35,074	28,020
Capital Equipment........	970	1,500	1,500	1,070
Subtotal................	15,575	36,574	36,574	29,090
Engineering and Geosciences				
Operating Expenses.......	18,915	26,675	26,675	26,675
Capital Equipment........	1,150	1,500	1,500	1,500
Subtotal................	20,065	28,175	28,175	28,175
Advanced Energy Projects				
Operating Expenses.......	9,060	10,602	10,602	10,602
Capital Equipment........	310	320	320	320
Subtotal................	9,370	10,922	10,922	10,922
Biological Energy Research				
Operating Expenses.......	10,534	12,455	12,455	12,455
Capital Equipment........	400	560	560	560
Subtotal................	10,934	13,015	13,015	13,015
Program Direction				
Operating Expenses.......	3,518	3,765	3,765	4,100
Subtotal................	3,518	3,765	3,765	4,100

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
Total				
Operating Expenses.........	$294,090	$341,471	$341,471	$343,181
Capital Equipment..........	24,280	31,120	31,120	30,494
Construction...............	17,160	49,970	49,970	36,125
Basic Energy Sciences........	$335,530	$422,561a/b/c/d/	$422,561	$409,800e/
Staffing Total FTE's.........	61	63	63	63

Authorization: Section 209, P.L. 95-91

---

a/ FY 1985 amount does not reflect a reduction of $8,640,000 for IG audits, prior year deobligation Management Initiative Savings.

b/ FY 1985 total reflects a reduction of $3,015,000 for Management Initiative Savings, other than IG audit/deoblgiations, contained in the FY 1985 President's Request.

c/ FY 1985 total reflects a reduction of $2,940,000 for ADP general reduction.

d/ Reflects savings of $229,300 for Section 2901 of the Deficit Reduction Act of 1984 (P.L. 98-369).

e/ FY 1986 total reflects a reduction of $8,080,000 for FY 1986 Management Initiative Savings, other than IG audit/deobligations.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF CHANGES
ENERGY SUPPLY RESEARCH AND DEVELOPMENT
(In thousands of dollars)

1985 Appropriation enacted	$422,561
1986 base	422,561
Program increases and decreases:	
Operating Expense Changes	
Materials Sciences	
o Permits selected increases required to continue major user facilities operations and will continue the core research program	+5,441
Chemical Sciences	
o Continues the core research program and major user facilities operations	+0
Nuclear Sciences	
o Permits selected increases required to continue major user facility operations and continues core research program	+2,988
Applied Mathematical Sciences	
o Continues support for the core research program. Funding support to the Supercomputer Center at Florida State University will be discontinued	-7,054
Engineering and Geosciences	
o Continues the core research program	+0
Advanced Energy Projects	
o Continues the core research program	+0
Biological Energy Research	
o Continues the core research program	+0
Program Direction	
o Impact of the Presidentially proposed reduction for the 5% decrease in salaries and benefits	-140
o Provides FY 1986 program support of 63 FTE's	+475
Subtotal, Operating Expense Changes	$+1,710

Capital Equipment Changes	
o Equipment funds will be restricted to meet essential replacements and upgrades required in support of the core research program	-626
Construction Changes	
o Continues funding for General Plant Projects; Accelerator Improvement Projects; Kansas State University; National Synchrotron Light Source; Center for Advanced Materials; and Stanford Synchrotron Radiation Laboratory Enhancement. Funding for the Catholic University project has been completed. Funding support for Columbia University project will be discontinued..	-13,845
1986 budget request	$409,800

Overview

The FY 1986 request for the Basic Energy Sciences (BES) program is $409,800,000. The request is composed of $343,181,000 in operating funds, $30,494,000 in equipment funds, and $33,125,000 in construction funds. In total, this budget request represents a decrease of $12,761,000 from 1985 but will continue all essential elements of the FY 1985 program. To meet this objective it proposes selected reductions to meet the budget levels of the President's Deficit Reduction Program.

In determining the appropriate Federal roles in the support of research and development, the Administration has identified support of long range basic research as the particular responsibility of Government, and further states that "mission agencies should support the foundation of basic sciences, as well as mission-oriented applied research, in appropriate disciplines." The Department request for BES is responsive to these roles.

The principal focus of the BES program is energy, but a number of other important national goals also are supported. Because of the ramifications of technical breakthroughs, national security, U.S. leadership in science and technology, and training all are served by a continuing aggressive program in basic research.

Improvements in existing technologies and the development of new technologies usually come from the application of new scientific knowledge. In FY 1984 a major new materials initiative was undertaken that not only attempted to deal with advanced materials research but also with aspects of training new researchers and interaction with industry. This initiative will continue in FY 1986. Similarly, initiatives in other areas have been started or proposed, all with substantial scientific community support.

The BES research program involves selection and continuation of projects of merit when viewed in relation to the Nation's diverse needs for energy, and selects those topics that, when taken as a whole, comprise an optimal, balanced program of mission-oriented basic research. To carry out this program, BES plans, supports and administers energy related research in the physical, biological and engineering sciences. New scientific information in these areas addresses the Administration's goals by providing the fundamental scientific and engineering base on which the Nation's future energy options depend. The strategy continues to be to:

o Provide critical knowledge and data and develop trained scientific talent through support of highly competent scientists in DOE mission areas;

o Provide for, and support operation of unique, specialized research facilities;

o Maintain liaison with other DOE programs, Federal agencies and the scientific, academic and industrial communities;

o Seek the scientific and industrial communities' assistance for the identification of needs and opportunities for research in areas likely to be relevant to future energy options; and

o Promote early applications of the results of basic research.

To continue its effectiveness, the BES program must: 1) maintain a strong core program -- this involves equipping, supporting and encouraging the scientists involved in our current program activities, and the training of new, younger scientists, to expand the forefront of knowledge in areas likely to be important to future energy technologies; 2) continue to support existing, unique facilities important to research in the U.S. while at the same time providing for needed new facilities and their operation; and 3) create opportunities for exploiting new, emerging areas that have been identified as having great potential importance to energy.

In support of basic research activities, BES funds a number of national user facilities. Four such facilities brought on line in the past several years are: the National Synchrotron Light Source at Brookhaven National Laboratory (BNL), the Intense Pulsed Neutron Source at Argonne National Laboratory (ANL), and the 1.5 Mev high voltage electron microscope at Lawrence Berkeley Laboratory (LBL), all of which became operational in FY 1983; and the Atomic Resolution Microscope at LBL, where the first full year of operation was FY 1984. Each provides new extended experimental capabilities and promises to open whole new areas of research heretofore not accessible. BES also has the responsibility for the operation of the Stanford Synchrotron Radiation Laboratory (SSRL) transferred to DOE from the National Science Foundation (NSF) in FY 1983, and the Proton Storage Ring/Spallation Neutron Research Facility at Los Alamos National Laboratory (LANL) which will begin operation in FY 1985. These new major facilities together with existing ones continue to place an added burden on BES to provide the additional funding needed for their operation at levels commensurate with the needs of the researchers.

The BES program also supports special research contracts and grants in which costs are shared by the universities. The universities' contributions are provided by a number of mechanisms, e.g., salaries to investigators, summer student assignments, provision of facilities and/or equipment, etc.

	FY 1984	FY 1985	FY 1986 Request
Materials Sciences			
Operating Expenses	$124,560	$133,055	$138,496
Capital Equipment	12,780	15,450	15,450
Construction	16,440	43,620	28,995
Subtotal	153,780	192,125	182,941

The goal of the Materials Sciences subprogram is to increase the understanding of topics related to the science of materials, which will contribute to meeting the needs of present and future energy technologies. The Energy Research Advisory Board (ERAB) placed the highest relative program priority ranking on this area of research in a review in 1981 of major energy science and technology-base programs and confirmed the high quality and importance of the Materials Sciences subprogram in last year's study of all materials research and development in the Department. This finding also was included in testimony in 1982 by the Chairman of ERAB to two House Subcommittees.

It is well known that materials technology plays a crucial role in developing new high technology industries in addition to increasing productivity of existing industries. This is because research in materials technology pushes forward the frontiers of knowledge and trains new scientists in this fundamental, highly interactive technical area, in addition to working on the long range problems of energy systems. Materials problems and limitations often restrict the performance of current energy systems and the development of future systems. A few examples of such problems and limitations include: degradation of mirror materials and low conversion efficiency of photovoltaic materials for solar energy; degradation of materials properties due to irradiation in fission and fusion energy systems; thermal and mechanical instabilities of materials for heat engines; corrosion and erosion of materials for coal conversion plants; long term environmentally compatible materials for containing nuclear waste; and light weight electrochemically stable materials for vehicular battery systems.

While each Federal agency conducts materials research to meet its own particular objectives, coordination across agencies is readily accomplished through established committees and interactions. In the area of basic materials research, the Materials Sciences subprogram coordinates its research most directly with the NSF's Materials Research Division and the more basic programs of the Department of Defense. The unique aspect of the Materials Sciences subprogram is the focus on energy related research and the use of advanced diagnostic techniques made possible by state-of-the-art research facilities supported by this subprogram. These activities complement the NSF and other agency programs. For example, there is relatively little work in the NSF program in radiation effects, corrosion-erosion related to fossil energy systems, solar photovoltaic materials, or nuclear waste isolation materials, whereas the Materials Sciences subprogram has very significant efforts in these areas.

This subprogram also has large efforts in facility-related research such as neutron scattering, synchrotron radiation research and electron microscopy, compared to the relatively small efforts in the NSF program.

The Materials Sciences subprogram has traditionally provided for the development, construction, and operation of large facilities for the total national program. Use of these major facilities is now formally open to all qualified researchers. A recent survey of 12 of the collaborative research centers under the purview of the Materials Sciences subprogram has shown that they accommodated about 900 users. The users came from DOE laboratories (21 percent), universities (48 percent), industry (14 percent), and the remainder from other organizations. The replacement cost for these facilities is estimated at $450,000,000. The Materials Sciences research funding at these facilities in FY 1984 was about $17,000,000 with another $13,000,000 being attracted from outside the Materials Sciences subprogram.

The field of materials sciences is timely for exploitation as a result of many new advances. We are approaching the ultimate resolution in microscopy. Significantly enhanced spectroscopic methods are now available, or will become available soon with new synchrotron radiation sources and neutron sources. Availability of high speed computers will help in understanding the theory of material science. Coupling these experimental and theoretical advances with our improved ability to prepare new materials will open up opportunities to design materials from fundamental principles and overcome or circumvent known and anticipated energy related materials problems.

Some of the needs to which the Materials Sciences research ultimately contributes include:

- Developing new or substitute materials,
- Tailoring materials to satisfy defined requirements,
- Predicting materials problems and service life,
- Improving the ability to successfully attack unforeseen materials problems in advanced energy systems, and
- Improving the theoretical and experimental capability to analyze the fundamental structure of materials.

To provide the new knowledge and information to meet these needs, Materials Sciences, comprised of the subfields of metallurgy, ceramics, solid state physics, and materials chemistry, places emphasis on selected generic areas of fundamental importance and on areas where problems are known to exist or are anticipated. Some research is directed at a single energy technology (e.g., photovoltaic materials for solar energy conversion), some research would have applicability to many technologies simultaneously (e.g., embrittlement of structural materials due to the presence of hydrogen), and still other research has more fundamental implications underpinning all materials research (e.g., mechanisms of atomic transport of solids). The research is conducted among a variety of institutions--national laboratories, universities, and to a lesser extent, industry, utilizing the talents of metallurgists, ceramists, solid state physicists, and materials chemists.

In addition to maintaining an appropriate mix among long-term science, multi-technology and single energy technology oriented research, a balance must be retained between forefront large facility-related research and small individual projects. Certain types of research simply cannot be conducted without large facilities (e.g., neutron sources with significant fluxes of neutrons cannot be made in "small" sizes). Also newer instruments with significant improvement in capability (e.g., synchrotron radiation sources) are very expensive to build and operate. This subprogram, therefore, continues to review the operating cost of existing facilities relative to their research contribution and also funds a modest level of research on new capabilities which can provide advances in science and technology. The Materials Sciences subprogram currently supports research and/or operation of several major facilities which are utilized in the pursuit of its research goals, including the National Synchrotron Light source (NSLS) BNL, High Flux Beam Reactor (HFBR) BNL, High Flux Isotope Reactor (HFIR) Oak Ridge National Laboratory (ORNL), Intense Pulsed Neutron Source (IPNS) Argonne National Laboratory (ANL), Proton Storage Ring (PSR)/Spallation Neutron Research (SNR) facility LANL, Low Temperature Neutron Irradiation Facility (LTNIF) ORNL, Surface Modification and Characterization Laboratory (SMCL) ORNL, and Electron Microscopes at ORNL, ANL, LBL, and the University of Illinois. These facilities also are available to qualified users outside the national laboratory complex.

The university portion of the program will be maintained at about 20 percent. When including Ames Laboratory (Iowa State University) and Lawrence Berkeley Laboratory (University of California) the support going to universities is 37 percent. At the FY 1986 requested level, research will be strengthened or initiated in selected technical areas at the expense of other lower priority projects resulting in an overall decrease in the level of research. Areas identified for emphasis generally fall into two categories of objectives: 1) synthesis, alloying, and preparation of new materials and structures, or 2) materials characterization and property measurements using highly advanced techniques. Areas within the first category include: high field superconductors, polymeric materials for high temperature or high conductivity applications, catalysts such as those incorporating artificial enzymes, new high temperature or corrosion resistant coatings, tailored materials with layered structures, advanced systems for synthesizing multicomponent materials, advanced structural ceramics, materials with nonequilibrium structures, and materials having nonlinear behavior. In the second category, emphasis will be on the use of advanced computational capability of highspeed computers to predict materials properties, studies of surface and interfacial phenomena using theory and techniques such as synchrotron radiation, the use of high resolution and analytical electron microscopy to characterize materials, the use of cold neutrons to investigate organic materials and defects in solids, and studies relating the structure of solids to their ultimate mechanical behavior.

The Materials Sciences subprogram is *the* basic materials program in the agency underpinning all the energy technologies. Materials play a crucial role in the development of energy systems. Coordination among the agency's materials programs takes place primarily through the Energy Materials Coordinating Committee. Within the Federal Government, the subprogram is coordinated in part through the interagency Committee on Materials (COMAT) and the basic Interagency Materials Group. At the Federal program level, Materials Sciences continues to represent about one-third of the Federal Government support for basic materials research.

Both directly and indirectly this subprogram supports the development of a national position on materials research. The ability to provide such support stems directly from the experience and continuity within the Materials Sciences subprogram. The fundamental understanding of materials obtained in this subprogram has led to new approaches to alloy design for critical materials substitution, new materials with superior properties and advanced characterization techniques. Materials Sciences is recognized throughout the research community for its excellence. Past technical accomplishments have moved into the technological or commercial sector (e.g., radiation resistant alloys, glassy metals, ion implantation techniques for surface modification, and superconducting wire), and it is expected that through the proven methods of technology/information transfer and effective management this year's materials understanding or in some technological application in the future. Industrial interactions with this subprogram are encouraged and indeed have been successful. (The large number of patents issued under this subprogram is further evidence of the strong and appropriate technology orientation.) Significant progress was made during the past year in many areas of the subprogram. Some examples of recent accomplishments include:

- The operation of a newly designed diamond anvil pressure cell to attain a static pressure of two and one-half million atmospheres. This is nearly twice the pressure heretofore attained and will permit the investigation for the first time of the theoretically predicted superconducting properties of hydrogen as well as the creation of new classes of materials.

- The synthesis of metallic glasses at low temperatures without rapid cooling from the liquid state, by directly reacting crystalline materials with certain rapidly diffusing elements. Atoms in a metallic glass do not have a regular repeating pattern as in crystalline materials. This accomplishment portends the possibility of preparing bulk (as opposed to thin ribbons) metallic glasses, thereby making metallic glasses with their enhanced properties accessible to a wider range of applications.

- The definitive delineation of a new brittle cracking mechanism in stress corrosion cracking. A new experimental observation on stress corrosion cracking in ductile alloys showed that cracking proceeds up to one thousand times more rapidly than previously predicted. Altered surface layers were found to change the fracture mode from ductile to brittle in normally ductile metals. This discovery has positive implications for understanding and controlling the stress corrosion cracking of ductile alloys such as stainless steels.

Operating and Capital Equipment Request

The FY 1986 requested level for the Materials Sciences subprogram will provide for research continuity although at a lower level than the previous year and permit a reasonable level of utilization of major facilities. Strengthening of important topical areas and initiation of some new thrust areas recommended by workshops, panels of the Council on Materials Science and materials aspects of National Academy of Sciences studies will be undertaken at the expense of other research. In general, the major user facilities such as HFBR, NSLS, IPNS, and the NCEM will operate at minimum reasonable levels in the requested budget. The requested level will permit continuation of research at the Center for Advanced Materials (LBL) and elsewhere in ceramics, polymers, electronic materials, layered compounds and materials tailored for specific property optimization. For energy systems, new advanced materials are essential to achieve the required difficult efficiency improvements.

The increase in operating funds of $5,441,000 to a total of $138,496,000 will be used to permit a reasonable level of utilization of major user facilities. The requested operating level will allow for continuation of the core program of research with some strengthening of research on advanced materials preparation and materials characterization research at the expense of other research. The capital equipment request is $15,450,000, no change from the previous year. This modest budget is needed in order to replace outmoded equipment and allow for some potential for new avenues of research in electron microscopy and neutron and photon scattering spectroscopy.

Construction

The FY 1986 request for Materials Sciences for construction will permit a continuation of projects approved in FY 1985. At the Stanford Synchrotron Radiation Laboratory (SSRL) funds of $2,560,000 are requested in FY 1986 to complete the upgrade consisting of accelerator improvements and small laboratory additions to SSRL totalling $12,930,000. At Brookhaven National Laboratory, funds of $7,200,000 are requested in FY 1986 for the National Synchrotron Light Source (NSLS) beam lines and building expansion project totalling $19,700,000. At Lawrence Berkeley Laboratory, funds are requested in FY 1986 for continuation of the Center for Advanced Materials project, consisting of two buildings--a Surface Science and Catalysis Laboratory and an Advanced Materials Laboratory. The request is for $17,440,000 out of a total project cost of $40,250,000. Accelerator and Reactor Improvements and Modifications (ARIM) funds of $1,795,000 are also requested for the existing facilities at BNL, the High Flux Beam Reactor (HFBR) and the NSLS. Further details for each of the construction projects are provided in the attached construction data sheets.

	FY 1984	FY 1985	FY 1986 Request
Chemical Sciences			
Operating Expenses	$ 75,165	$ 79,495	$ 79,495
Capital Equipment	6,520	8,840	8,840
Construction	450	6,050	5,830
Subtotal	82,135	94,385	94,165

The goal of the Chemical Sciences subprogram is to build the knowledge base needed to improve energy technologies and lead to new concepts. Chemical and physical phenomena in this framework are studied at the forefront of science, with concurrent training of future energy scientists. Two independent reviews have confirmed the quality and importance of the subprogram. The Energy Research Advisory Board placed Chemical Sciences in the highest relative priority programs needing additional funding. Futher strong evidence of the program's importance flows from a recent intensive study by a National Academy of Science Committee, which stated "Chemistry is a central science that provides fundamental understanding needed ... to tap new sources of energy..." and "Our future international competitiveness will depend upon maintaining our present leadership position in the chemical sciences."

The Chemical Sciences effort is focused on energy related science. To assure sound management the subprogram is coordinated closely with other Federal agencies which have different missions. This is accomplished by frequent individual contacts and periodic meetings of the Federal Interagency Chemistry Representatives.

Within the broad scope of this subprogram certain areas receive emphasis because they are perceived to have clear bearings on recognized or anticipated energy technologies. These are: photochemistry (including photoelectrochemistry), chemical physics (including areas related to combustion), atomic physics (especially as related to magnetic fusion), the basic chemistry of coal, catalytic phenomena, separations, analytical techniques and chemical thermodynamics.

Photochemical researchers are probing the precise molecular arrangements by which nature achieves the conversion of solar energy to chemical energy, and are also moving toward the knowledge necessary to create solar cells to produce hydrogen from water.

Researchers in chemical physics are contributing to understanding of the complex chemical sequences which determine how rapidly, completely and cleanly a flame burns and fuel is consumed. Advanced techniques are being used to answer questions about the behavior of active species which are present in many energy processes, oxygen atoms for example.

Atomic physicists (not to be confused with nuclear physicists) are achieving remarkable progress, with use of several different ion accelerators, in elucidating the properties of highly charged ions which may act as harmful traps for energy in magnetic fusion plasmas. The behavior of such ions at energies higher than those found in fusion systems is also being studied.

Two very different approaches are being taken toward obtaining the knowledge which will ultimately enable engineers to achieve the economical conversion of coals to gaseous and liquid fuels. One is to learn the molecular structures of coals in order to produce more useful products. The other is the study of catalysis to provide knowledge for technologists who need to design catalysts for selectively converting coal products into simple fuels and chemicals. A catalyst facilitates a chemical reaction but remains unaltered in the process.

Separations which use chemical as well as physical means are common in energy operations: for example, separating a valuable fuel from complex mixtures. Separation processes consume large amounts of energy which often make the difference between economical and nonviable processes. Chemical Sciences supports basic research in separations, seeking knowledge which is widely applicable. Research also is conducted on analytical techniques, since it is important to be able to identify and measure exactly the chemical species present in a fuel of unknown purity, or in other mixtures which might require purification.

The engineering design of major plants for production or handling of fuels requires reliable thermodynamic data on the behavior of the fuels in question. Such data are largely unavailable at this time for many mixtures of present or potential importance. It is thus necessary to have methods of calculating those data more reliably since measuring them for every mixture of interest would be time consuming and expensive. In fact it is unlikely that the needs could be met by experiments alone in a reasonable time. Chemical Sciences therefore supports research aimed at the ability to predict such data from known relationships using simple measurements on pure components.

A small but increasing fraction of the research is conducted at two major facilities which were constructed, and are now operated, by Basic Energy Sciences for use of both DOE-supported scientists and qualified visiting users. They are the Combustion Research Facility (CRF) and the National Synchrotron Light Source (NSLS).

At the CRF, Chemical Sciences not only provides the entire support for operation of the facility, advancing the state of the art of its unique laser systems and providing research space and assistance to visiting scientists, but also supports the major part of the Facility's internal research program. The visiting scientists come from academia and industry, especially the automobile industry. The in-house research emphasizes the development and use of advanced diagnostic techniques which probe flame temperature profiles, identifies key but short lived flame constituents and measures their quantities in different locations within flames.

At the NSLS, Chemical Sciences funds nearly 40 percent of the facility's operating costs and a large fraction of the BES supported in-house research. Among the research areas supported are: ultraviolet light photochemistry, electronic interactions between surfaces and adsorbates, and photon excitation and ionization of neutral atoms or molecules. Each of these areas is fundamental to understanding of energy processes which can be used by energy technologists in enhancing present systems or devising new ones.

The intent of the Chemical Sciences subprogram is to pursue knowledge at the cutting edge of the science. In some projects the relationship to a technology is recognizable and clear, as in the research on coal chemistry. In other projects the near term involvement with energy is less clear and the specific kind of technology cannot yet be identified because the science is too new.

Important progress was made in many areas of the subprogram this past year. Some examples of recent accomplishments include:

- Identification of new catalytic steps which may lead to new ways to convert carbon monoxide into methanol and other hydrocarbons. A dissolved lead oxide catalyst has been discovered to convert carbon monoxide and water into formate ions, which interact with each other to form the methanol. Work is in progress to examine the hydrocarbon possibilities.

- A new technique was developed for nonintrusive measurement of the fraction of gas bubbles in a gas/liquid flow system. It measures the echo from a radio frequency pulse into the two phase fluid which flows through a nonuniform magnetic field. The method can measure variations of void density in both time and space with either steady or unsteady flows. One prime candidate for its use is in power plants to monitor their efficient and safe operation.

- The first measurements of the absolute value of initial energy transfer by a beam of electrons interacting with large nonspherical molecules (cesium bromide) have opened the way to understand the performance of rare gas/halogen lasers. This fills a need in laser technology which could not be met before because the transfer of energy in collisions between electrons and molecules that cannot be approximated as point shapeless particles is very difficult to measure and nearly impossible to predict theoretically.

Operating and Capital Equipment Request

The request for operating funds is $79,495,000, the same as appropriated for FY 1985. The requested funding level of the Chemical Sciences subprogram will sustain most of its projects but will require some cutbacks due to unmet inflation in the cost of performing advanced research and of operating major research facilities. Thus, some selective termination of projects will be necessary. The FY 1986 operation of the NSLS will be funded at the same amounts as in FY 1985 ($5,350,000), as will the operation of the Combustion Research Facility ($3,375,000). In the CRF case, since Chemical Sciences is the sole source of funds for operation of this facility, its ability to accommodate visiting user scientists will lose some ground.

The request of $8,840,000 in capital equipment funds is the same as in FY 1985. The request includes general purpose equipment for two laboratories: $2,000,000 for ANL and $140,000 for the Ames Laboratory. The balance of the request will go to meet the continuing need for forefront, up-to-date instrumentation for use of the scientists in the Chemical Sciences subprogram. In the competitive areas in which they operate, today's advanced chemical researchers depend on modern, sophisticated instruments, many of which range in cost into hundreds of thousands of dollars apiece. Sharing of these instruments among researchers is, thus, strongly encouraged by the BES program.

Construction

The request for construction funds is $5,830,000, which is $220,000 less than the 1985 level. There are four general plant project items representing overall landlord responsibilities: $3,000,000 for ANL, $600,000 for the Ames Laboratory, $300,000 for the Combustion Research Facility, and $30,000 for the Notre Dame Radiation Laboratory. The ANL need is especially important since it continues the recovery of plant efficiency after several years of dramatic budget stringency. Details are given in the attached construction data sheet 86-R-400.

The balance of construction funds requested, $1,900,000, is to continue construction of the Ion Collision Physics Facility at Kansas State University, the United States' first state-of-the-art accelerator based atomic physics facility. The project was initiated in FY 1985 with a total estimated cost of $3,400,000. This has been increased to $5,100,000 by including additional costs necessary to the success of this Facility. The additional costs comprise increased prices of the required components, the assembling, testing and adjusting of the new accelerator, a computer necessary for coupling the accelerators and detectors and a contingency allowance adjusted for inflation. Details of this construction project are described in the data sheet 85-ER-403.

	FY 1984	FY 1985	FY 1986 Request
Nuclear Sciences			
Operating Expenses..........................	$ 37,733	$ 40,350	$ 43,338
Capital Equipment..........................	2,150	2,950	2,754
Construction................................	270	300	1,300
Subtotal................................	40,153	43,600	47,392

The Nuclear Sciences subprogram encompasses five principal activities: (1) measuring, compiling and evaluating nuclear data for both fission and fusion energy technologies; (2) advancing the knowledge and understanding of the actinide elements' chemical and physical behavior; (3) providing isotopically enriched samples of ordinary elements and samples of the man-made transplutonium elements for research, medical and industrial uses; (4) operating the Stanford Synchrotron Radiation Laboratory for the broad community of synchrotron radiation researchers and (5) conducting research on heavy ion accelerator technology and preparing for its evaluation as a driver for use in inertial confinement fusion systems.

Nuclear Data

The goal of the Nuclear Data activity is to establish and maintain an accurate, complete, and accessible nuclear data base to meet long-term needs of the fission and fusion energy technologies and to support nuclear waste management and weapons development activities of the Department. The United States nuclear data effort is a well-integrated, time-tested activity involving data measurement, compilation, evaluation, processing, and dissemination. Measurement work is centered at the Oak Ridge Electron Linear Accelerator and the Argonne Fast Neutron Generator; the compilation and evaluation efforts are centered at the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory. The request for FY 1986 ($9,682,000 operating expenses and $600,000 capital equipment) reduces overall this subprogram's nuclear data activities by about five percent below FY 1985 levels.

The Nuclear Sciences subprogram provides for management and oversight of the national nuclear data system. In coordination with this subprogram, other nuclear-based programs (Nuclear Energy, Fusion Energy, Nuclear Regulatory Commission, and Defense Programs) participate in this activity through the Cross Section Evaluation Working Group (CSEWG) and by supporting data activities of specific, near term importance to their respective technologies. The light water reactor industry participates in CSEWG activities and provides funds for special data projects through the Electric Power Research Institute (EPRI). Nuclear data needs are documented in great detail and are regularly updated: for fission technology, as a part of the duties of the CSEWG; for fusion technology, as a part of the duties of a special working group of the United States Nuclear Data Committee. The Office of Fusion Energy provides direct input to this special working group.

Plans and tentative schedules have been drawn up for the production of the next version of the Evaluated Nuclear Data File, ENDF/B-VI. In FY 1986, work on ENDF/B-VI will include reevaluation of fissile and fertile nuclear data files in the resolved resonance region, reanalysis of Cr, Ni, and Fe (structural materials) files, and reevaluation of fission product data files. In support of fusion energy technology, ENDF computer formats will be extended to permit the inclusion of more detailed data and to make the file more useful for applications involving higher energy neutrons and low energy charged particles. An important evaluation effort is currently under way involving scientists from the National Bureau of Standards (NBS), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Brookhaven National Laboratory (BNL), and Argonne National Laboratory (ANL), who are attempting for the first time a simultaneous best fit to the major "standards" cross sections used in ENDF, incorporating all available information on the covariances or correlations among measured data.

Another major data base activity, the Evaluated Nuclear Structure and Data File (ENSDF), is supported entirely by Nuclear Sciences (with the exception of non-U.S. participants) and consists of a network of evaluators of "mass-chains" in the United States and abroad. Coordination, assembly, and production of the data file and the important continuing publication of revised "Nuclear Data Sheets" is performed by the NNDC. The United States ENSDF evaluation effort includes work at BNL, Idaho National Engineering Laboratory (INEL), Lawrence Berkeley Laboratory (LBL), ORNL, and the University of Pennsylvania. A "Radioactivity Handbook" based on ENSDF is being prepared at LBL and is scheduled for publication early in 1985. This handbook has been designed to be a quick reference guide for users of nuclear data for industrial, medical, and engineering applications.

Nuclear model code work will continue in FY 1986 with the objective of developing methods for accurate estimation of needed cross sections for reactions which have not or cannot be experimentally determined. An innovative approach has been developed at ORNL for understanding uncertainties in nuclear data. This new technique utilizes group theory as the fundamental method for treating in a coherent fashion systematic and statistical uncertainties. Uncertainty analysis of experimental measurements is now being performed utilizing this new technique. Results are important for sensitivity analyses of nuclear data to determine the accuracies to which cross sections must be measured in order to meet needs of the fission and fusion energy technologies.

The Nuclear Data activity includes a nuclear data measurement effort in which the talents of experienced nuclear physicists are used at appropriate facilities to perform the difficult, painstaking measurements required to improve the data base. The major effort is carried out at the Oak Ridge Electron Linear Accelerator (ORELA) and the Argonne Fast Neutron Generator (FNG). At ORELA, neutron cross sections can be measured efficiently with great resolution and over a wide range of energies. University groups at Denison University (Ohio) and Middle Tennessee State University collaborate with ORNL staff in experimental work at the ORELA. The FNG provides unique measurement capability in the multi-MeV energy range.

Facilities at the ORELA and FNG are used to make measurements for neutron-induced reactions on materials of interest to fusion energy. Experimental apparatus and techniques used for neutron and gamma-ray emission measurements have been improved and are being used to meet fusion energy requirements for these cross sections. A new, high-resolution gamma-ray detector system for ORELA has been developed and tested and will be used in FY 1986 to further understanding of neutron inelastic scattering processes. In addition, gamma-ray measurements will provide very useful information on tertiary reactions, for example, (n,2n) and (n,xnp) reactions. Detector systems are being designed and tested to extend the capability of ORELA to measure neutron-induced charged-particle spectra over a wide range of neutron energies and outgoing angles. In FY 1986, FNG work will include activation and dosimetry cross section measurements in the 10 to 14 MeV energy range.

ORELA work also includes the measurement and analysis of neutron cross sections for materials of importance to the fast reactor program. These are primarily cross sections and related quantities for fissile and fertile reactor fuel materials, with emphasis on neutron energies below 0.3 MeV. Also, cross sections measurements in the thermal neutron energy range for the fissile and fertile nuclides are planned in FY 1986 in support of light water reactor data needs. In FY 1986, FNG work in support of fission energy technology will emphasize fast neutron radiative capture measurements on actinides (e.g., Th-232 and U-238) and on fission products.

Heavy Element Chemistry

Basic research is supported which will strengthen our understanding of the chemical, physical and nuclear properties of the actinide elements. Two purposes are served. One is to enhance knowledge of these elements to meet technological needs in connection with their industrial use as neutron sources in medicine, gauges, etc., and their behavior in spent nuclear fuels. The other is to gain insights into the chemistry and physics of elements in other parts of the periodic table through enhanced theoretical insights gained by virtue of the actinide elements' position near the limit of the periodic table.

While some of this research is conducted at universities, most of it takes place at DOE laboratories because of health and safety requirements for handling these materials. University researchers in this field typically spend much of their time at the DOE laboratories, taking advantage of their special facilities and collaborating with the laboratory scientists.

Some recent accomplishments illustrate the nature of this activity.

- A new concept has been developed for improved cleanup of uranium hexafluoride (UF_6) process streams. Basic chemical studies found that gaseous metal fluoride impurities, such as neptunium hexafluoride, will react with solid uranium pentafluoride to form gaseous UF_6 and solid lower valence fluorides of the impurity metals. After this removal of the impurities from the gas stream, the trapped impurities can be recovered photochemically. Other streams can be similarly cleaned.

- Thermodynamic studies have provided guidelines for handling actinide elements in candidate synthetic mineral hosts for nuclear wastes. The relative stabilities of different valence states of different actinides in these mixed-metal oxides (perovskites) have been measured with the finding that preparation methods must be adjusted so as to avoid the much more leachable hexavalent state of whatever actinide is to be contained.

The FY 1986 request for operating funds for Heavy Element Chemistry is $4,705,000. This is an increase of $390,000 above FY 1985 and is needed in order to restore this activity to the FY 1984 level. The capital equipment request of $350,000 is the same as FY 1985 and will be used for upgrading instrumentation, an especially critical aspect of this research area.

Isotope Preparations

Isotopically enriched samples of individual elements are produced in the electromagnetic isotope separation facility (Calutrons) at ORNL. They are provided by sale or loan to industrial and medical users and to research scientists, both domestic and international. Most of the samples produced at the Calutrons are nonradioactive isotopes, which are highly important to several areas of research and development including those related to fission and fusion power. They are also required as targets for manufacture of radioactive isotopes for medical diagnostics. A recent operational improvement is noteworthy:

- Until now, separation of isotopes has been limited to only one element at a time within a single magnet segment. Modification of operating methods now permits the separation of isotopes of more than one element at a time during a run which may last many months.

Two closely associated facilities in the Isotope Preparations activity are the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL) and the Transuranium Processing Plant (TRU) at ORNL. HFIR serves two principal missions: formation of research quantities of the higher actinide elements by neutron irradiation and provision of an exceptionally high flux of neutrons for studies of structures of matter as well as for neutron damage studies. (Other radioisotopes are also produced at HFIR, for research and other purposes.) TRU has only one purpose: the separation of radioactive elements in pure states from the media (such as HFIR targets) in which they have been formed. The HFIR/TRU combination presently is the only available source of californium-252, which is a uniquely useful portable source of neutrons, used in industrial, defense, medical and scientific applications.

The operating funds requested for Isotope Preparations are $16,957,000, an increase of $2,382,000 which is absolutely necessary if these national assets are to be kept operating to serve vital and widespread needs in the public and private sectors. Within this increase, $1,100,000 is required by the HFIR to maintain the operation costs of electricity, control plate fabrication, fuel grid procurement and chemicals, and providing the minimum professional and technical crew for safe operation. Also within the $2,382,000 increase is $700,000 for the TRU. This amount is required to minimize personnel radiation exposure in the interests of safety.

The third Isotopes Preparation facility is the Calutrons, for which an increase of $700,000 is urgently needed. This will provide the necessary core support for a very limited (6 month) operation, including minimal staff, power and utilities. Since the revenue from sales of isotopes for medical and other purposes is not predictable from year to year, such core support is required in order to maintain the facility's viability.

The request for capital equipment for Isotope Preparations is $680,000, a $30,000 increase above the amount appropriated in FY 1985. These funds are needed mainly for replacement and upgrading of the remaining old equipment at the 40 year old Calutrons, which continue to be the only source other than the U.S.S.R. of enriched isotopes in usable quantities.

Accelerator and Reactor Improvement funds of $1,200,000 are requested for safety improvements the HFIR. These funds are needed for two purposes. The first is replacing two heat exchangers which are corroding and nearing the end of their reliable lives. The second purpose is installing a remote sampling system within the reactor building, which would be needed in the event of a release of radioactivity. Although this is an unlikely event, safety considerations now dictate having such a new system.

Stanford Synchrotron Radiation Laboratory

The Stanford Synchrotron Radiation Laboratory (SSRL) is a major site of synchrotron radiation research in the U.S., particularly for the x-ray region of the spectrum. It is located at the Stanford Linear Accelerator Center (SLAC) and shares the use of the Stanford Positron-Electron Asymmetric Ring (SPEAR) storage ring with the High Energy Physics Program, the sponsor of SLAC. When SPEAR is operated solely for the production of synchrotron radiation, SLAC is reimbursed SPEAR operating costs by SSRL. The facility, sponsored prior to FY 1983 by NSF, is operated in the user mode, that is, all operating costs are provided by DOE (Nuclear Sciences subprogram). Qualified users from government, industry and university labs, whose proposals are peer reviewed, are not charged for facility use for basic research. A significant event occurred at SSRL during the past year--the installation of a 54 pole wiggler in a straight section of SPEAR which now provides the most intense x-ray beam in the world.

The request for operating funds for SSRL for FY 1986 is $7,116,000, an increase of $216,000 above the amount appropriated for FY 1985. This is an exceptionally tight funding level; it does not allow for the full inflation impact or the recently increased charges to SSRL for shared use of the Stanford Positron-Electron Asymmetric Ring which is the heart of the SSRL operation. This funding level, therefore, imposes on SSRL and its many scientific users a curtailed schedule of operation again in FY 1986. The FY 1986 capital equipment request totals $550,000, a slight reduction compared to FY 1985, the peak year of refurbishing SSRL's instrumention. general plant project funds ($100,000) are requested for necessary sewer improvements and the replacement of a high voltage power station.

Heavy Ion Fusion Accelerator Research

The goal of the Heavy Ion Fusion Accelerator Research (HIFAR) program is to develop heavy ion accelerator technology and perform appropriate ion beam experiments to the point where an adequate data base exists for evaluation of heavy ion inertial fusion drivers and their possible use in civilian power applications of inertial confinement fusion.

Transferred from the Office of Inertial Fusion within Defense Programs in FY 1984, the HIFAR program has been the subject of a number of reviews and technical workshops which have been uniformly favorable in their conclusions. In 1983 a two-stage plan was developed in connection with the transfer and was reviewed by a JASON Panel. The Panel judged the revised plan to be "---a sensible and minimal next step in Heavy Ion Fusion."

The HIFAR program is based on the need for experimental verification of the previous theoretical studies at an appropriate scale. Stage I involves the development of a "Multiple Beam Experiment" (MBE) to test the critical elements of promising accelerator technologies with particular emphasis on the use of multiple beams for cost reduction at high intensity. Stage II calls for a "High Temperature Experiment" (HTE) in which a high temperature (50-100 eV) solid-density plasma would be demonstrated. Currently planned for FY 1988-1990, the HTE would entail the construction of an accelerator suitable for verification of the design principles of a reactor-driver accelerator and for verification that target heating predictions are valid.

Demonstration of high temperature in a solid-density plasma would signify a major entry of accelerator technology into the parameter range needed for inertially confined fusion. It would settle questions relating to energy deposition and beam propagation, besides providing a crucial benchmark in the development of accelerators for fusion power. Given the established accelerator technology history that can guarantee repetition rate, efficiency, and reliability, Heavy Ion Fusion could then be evaluated as a serious candidate for a fusion power system for the next century.

In preparation for the High Temperature Experiment, it is crucial to have data from experimental tests on transport, acceleration, and the selected method for current amplification with the MBE. Issues to be addressed in Stage I include: predicted transport space-charge limits on multiple beams; stability, reproducibility, and reliability of intrapulse and pulse-to-pulse operation; accelerator cost reduction; preservation of beam quality including stability and containment of the high charge-density pulses; and designs for final compression, transport, and focusing of the beams to the target. Recent accomplishments include a major success in demonstrating single-beam high current transport with cesium ion beams.

Major FY 1986 milestones include multiple beam injector fabrication and testing, and completion of several prototype MBE accelerating and focusing cells. The principal experimental effort is conducted at the Lawrence Berkeley Laboratory, with Los Alamos National Laboratory providing multiple beam injector development.

The request for FY 1986 is $5,452,000, compared to $5,528,000 in FY 1985, and includes $4,878,000 operating expenses and $574,000 capital equipment. These funds are necessary for experimental hardware needed in Stage I of the program which, during FY 1985-1987, is dominated by purchases and fabrication of MBE hardware. The level of funds provides for completion of the MBE in FY 1988, one year later than projected in the 1983 plan (adjusted for FY 1985 funding).

	FY 1984	FY 1985	FY 1986 Request
Applied Mathematical Sciences			
Operating Expenses.........................	$14,605	$35,074	$28,020
Capital Equipment..........................	970	1,500	1,070
Subtotal................................	15,575	36,574	29,090

The Applied Mathematical Sciences subprogram will meet the immediate needs for large-scale scientific computing in the research programs supported by the Department's Office of Energy Research and the long-range needs of the Department in computational research. The program consists of two parts: Energy Science Advanced Computation and Applied Mathematical Sciences Supercomputing Research. This program will meet DOE needs and will make a substantial contribution to solving the national problems of providing access to researchers, particularly in universities, and maintaining U.S. leadership in supercomputer technology. The Energy Science Advanced Computation subprogram will provide large-scale scientific computing required by High Energy and Nuclear Physics, Basic Energy Sciences, and Biological and Environmental Research. This scientific computing will be provided through network access to supercomputers for contractors in universities, industry, and DOE national laboratories. The Supercomputing Research subprogram supports research in mathematical and computer science that is critical to the use by many DOE programs of the newly emerging multiprocessor supercomputer systems and the long-range development of future supercomputer systems.

In recent years, the modern supercomputer has changed the nature of scientific research and technology development. Computational science serves a role in research that is a hybrid between theory and experiment. In some cases, computations provide insights into experimental data, and in others, computations are used to simulate the ideal experiment to test an analytical model. The emergence of computational science as an important element in scientific research and technology development is the result of the development of our ability to do computational modeling of complex physical problems and the enormous power of the modern supercomputer. This combination allows scientists and engineers to model complex problems in a much more realistic way and to obtain much more accurate answers than was possible just 5 or 10 years ago.

Large-scale scientific computing now makes substantial contributions to many fields of research such as fluid dynamics, plasma dynamics, astrophysics, materials science, chemistry, atomic physics, etc. Similarly, large-scale calculations are making significant contributions to product development in areas such as nuclear weapons, electronics, automobiles, aircraft, and chemicals. In product development, computer modeling is used to reduce the number of design/test iterations which are so time consuming and expensive.

The Department of Energy (DOE) has made a significant commitment to large-scale scientific computing in several of its research and development programs. As an agency, DOE's commitment to scientific computers is not new; it is the largest user of supercomputers in the world. Historically, the Department and its predecessor agencies (the Atomic Energy Commission and the Energy Research and Development Administration) caused many supercomputers to be developed through its nuclear weapons design work at the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory. The supercomputers that were developed in response to DOE needs were delivered to the DOE laboratories nearly devoid of software, requiring our laboratories to develop the necessary software for a complete supercomputer system. Through the software development efforts and the continual interaction between DOE laboratories and the supercomputer vendors, DOE has made significant contributions to supercomputer technologies.

Great progress has been made in our ability to do computer modeling of complex scientific problems; there is, however, still a long way to go. Many of the Department's research and development programs have large, complex research and engineering problems to solve that can be only crudely approximated with today's supercomputers and mathematical techniques. There is a need to include more "physics" in the models, to use finer zoning for more accurate answers and to use more dimensions. In order to solve these complex problems to the accuracy desired in the future, computers with substantially increased computing power over those currently available will be required. Several DOE programs have estimated that they will require computers 200 times as powerful as a Cray-1 or a Cyber 205 by the end of the decade. In fact, some of the DOE programs could use that kind of computing power today, if it were available.

Applied Mathematical Sciences Supercomputing Research

The objective of the Applied Mathematical Sciences Supercomputing Research activity is to advance the understanding of the fundamental concepts of mathematics, statistics, and computer science underlying the complex mathematical models of the key physical processes in the Department's research and development programs.

The DOE scientific research community comprises a large fraction of this country's expertise in large scale computational modeling, with applications in fusion energy, weapons design, and fundamental physical sciences research. Much of the scientific research and development effort in DOE programs is focused directly on analytical and numerical modeling of physical processes. An understanding of the fundamental principles upon which these models are based is important for developing energy systems for the future. Thus, research in mathematical analysis, algorithms, and computational techniques is crucial in conducting most scientific investigations. DOE's lead role in the development and application of supercomputing techniques is based on this fundamental research.

One of the clear focuses for the Supercomputing Research activity is to develop our ability to use multiprocessor computer systems. The multiprocessor direction for supercomputers is dictated by the fact that only very limited gains can be made from increased component speeds and levels of integration in the future. This has caused computer architects to look to using more than a single processor working on a problem. The change from von Neumann (sequential) to multiprocessor machines represents an enormous change in scientific computing, greater than the challenge faced by the introduction of vector processors. The challenge with multiprocessors, is to have a large number of processors efficiently working simultaneously on the same problem. New software, languages, algorithms, and probably entirely new mathematical approaches to solving a number of scientific problems will be required. The Supercomputing Research activity has as one of its objectives, conducting the research on parallel computing necessary to ensure that the Department's programs using large-scale scientific computing will have the tools to use efficiently the new machines that will be produced commercially and to exploit their maximum capability.

The program funds basic research at many of the national laboratories, universities, and private research institutions in three major activities: Analytical and Numerical Methods, Information Analysis Techniques, and Advanced Computing Concepts. Analytical and Numerical Methods includes analytic and numerical techniques for solving systems of partial differential equations; Information Analysis Techniques includes data management and statistics; Advanced Computing Concepts includes software engineering and research on high performance systems. In addition, experimental computing capabilities are being established as research facilities to support the exploration of new concepts in large scale scientific computing. Regular meetings with program managers in other Federal agencies help coordinate these activities. Two such groups established to coordinate government sponsored research programs are the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) panel on high performance computing research and the Interagency Committee on Extramural Mathematics Programs (ICEMAP).

Recent accomplishments of the Applied Mathematical Sciences Supercomputing Research activity include the following:

o The Cosmic Cube, a 64 processor computer, is operational at Caltech

Researchers at Caltech have successfully built a 64 processor research computer with the equivalent computing power of one-tenth a Cray-1 at one-hundredth the price. This architecture is dramatically different from today's Class VI machines and early results indicate it may be a cost effective alternative for a variety of scientific problems. Recently a lattice gauge problem modeling the fundamental properties of matter ran for 2500 hours on the Cube providing scientists with some interesting results on the heavy quark potential with high statistics and demonstrating the reliability of the architecture. A variety of other problems have been implemented on this machine, including problems in astrophysics, molecular dynamics, geophysics, and critical phenomena in materials.

Research in very large scale integrated (VLSI) design on this project was supported by DARPA. The problem decomposition study, algorithm implementation in software, and mathematical research was supported by DOE. Intel Corporation donated the microprocessors for the machine and DEC donated much of the cost of the front end machines. This sort of university/industry/government collaboration represents the key idea for successful supercomputing research.

o Capillarity phenomenon mathematically predictable

Researchers at LBL and Stanford found that the solution of the equations governing liquid free surface interfaces predicts unexpected behavior if the cross-section of the tube is not circular. They concluded that the solution of the equations can behave discontinuously or even cease to exist when small changes are made in contact or capillary-tube cross-section. For example, when applied to the case of a wetting liquid in a tube of square cross-section in zero gravity, their analysis predicts that for contact angles greater than or equal to a critical value of 45 degrees the height of the free surface (portion of a sphere) is uniformly bounded, but for smaller contact angles no solution of the equation exists. This remarkable behavior was verified experimentally at the NASA-Lewis Research Center in their Zero-Gravity Drop Tower. It was observed in tests that for contact angles less than the predicted value the fluid flowed up along the corners rather than remaining simply contained in the bottom of the tube. While these findings have intrinsic mathematical importance, they may find applications in such practical areas as flow in heat pipes, growth of crystals in low gravity, behavior of petroleum in underground reservoirs, and other areas in which capillarity phenomena play a role. The effect of zero-gravity capillarity is important in space manufacturing and will be investigated further in an upcoming space shuttle flight experiment.

In FY 1985, an enhancement in the large scale scientific computing area was started, with emphasis on algorithms for large scale parallel architectures based on several experimental computer systems under study. The emphasis on new parallel multiprocessor architectures applies to all three activities of the research program: analytical and numerical methods for the solution of systems of differential equations, information analysis techniques, and advanced computing concepts.

The FY 1986 operating budget request for Applied Mathematical Sciences Supercomputing Research is $21,020,000, a slight decrease from the amount appropriated in FY 1985. This will provide a slightly reduced level of effort in research directed toward analytical, numerical, and advanced computing techniques that form the basis for maintaining DOE's lead role in the application of large scale computing for scientific research. The projects initiated in FY 1985 in universities and DOE laboratories aimed at investigating parallel architectures will be continued at a constant level of effort.

The three projects started in FY 1985 are at NYU, Cal Tech, and the University of Illinois. These three projects represent several investment strategies. The first is a collaboration with a large industrial partner providing the mathematical and computer science expertise for scientific applications with a DOE supported university (Courant Institute Mathematics and Computer Laboratory). The second represents a large DOE-supported university group providing again the mathematical and computational science expertise and a government sponsored laboratory providing the engineering design and implementation. The third represents a large, experienced university and laboratory group that is using mostly "off the shelf" components and that is at the forefront of development of software for scientific applications.

For FY 1986 $500,000 in capital equipment funds is requested, a decrease from the FY 1985 request of $600,000. These funds are used to equip the research computing facilities at the national laboratories and NYU/Courant Institute. Additional mass storage and network hardware will be acquired to ensure that wide access to the experimental and research computing facilities is available to all the universities and laboratories participating in supercomputing research.

Energy Science Advanced Computation

With the advent of modern supercomputers and the maturing of computational techniques, computational science has joined experiments and analytical theory as an equal, essential tool in the advancement of science and technology. Energy Science Advanced Computation provides computational support for the research programs supported by DOE's Office of Energy Research (OER). These OER programs include High Energy and Nuclear Physics, Basic Energy Sciences, and Biological and Environmental Research. The objectives for the Energy Science Advanced Computation activity associated with this computational service are:

- to provide access to modern, supercomputer systems for researchers that are funded through the OER programs;
- to prepare this research community to take full advantage of new, supercomputer technologies as they become available;
- to provide more productive and effective advanced software tools for supercomputer systems; and
- to shorten the time required to implement the results of the Supercomputer Research program into existing applications and systems software.

The ER researchers served by this program are geographically dispersed throughout the United States and had little access to supercomputers prior to FY 1985. The most cost-effective and expeditious method of initiating this access program in FY 1985 was to use the existing nation-wide Magnetic Fusion Energy (MFE) computer network. The network approach allows for the matching of resources to program requirements across all ER programs rather than on an institution by institution basis.

During FY 1985, an enhanced class VI computer system, compatible with the existing system at the MFE Computer Center, was installed at the Center on an interim basis to immediately alleviate the severe capacity shortage for the new ER users. A thorough analysis of the computational needs and capability requirements of all the ER programs was also performed. This analysis verified that the most powerful and capable computer systems available are necessary to support the on-going ER research and development programs.

During FY 1985, the Energy Science Advanced Computation activity initiated a Supercomputer Computational Research Institute (SCRI) at the Florida State University (FSU) as directed by Congress in P.L. 98-360. The purpose of the SCRI is to conduct research in computational science and to provide services to support the computational needs of the SCRI, FSU, and other ER funded research projects.

For FY 1986, a total of $7,000,000 in operating funds, a decrease of $7,170,000 from the FY 1985 appropriation, is requested. These funds will be used to continue this access program at the Magnetic Fusion Energy computer network. Due to fiscal circumstances in FY 1986, support for the SCRI will be discontinued. Also identified under this activity is a Major Item of ADP Equipment, a Class V computer system, at the Argonne National Laboratory (ANL) to replace obsolete systems, to alleviate current systems saturation, and to address the local ANL scientific computing requirements through FY 1989. Funds for this computer system are not included in this activity since they will be obtained on a full cost recovery basis across the programs which utilize the scientific computational facilities within the ANL. The total costs associated with providing supercomputer access for ER scientists are as follows:

1. $4,200,000 for the lease and maintenance of a class VI computer system for one year.
2. $1,800,000 for incremental support staff, supplies, utilities, services, etc. at MFECC necessary to operate the above class VI computer system.
3. $1,000,000 for other network communications costs and access facilities.

For FY 1986, $570,000 in capital equipment funds, a decrease of $330,000 from the FY 1985 appropriation, is requested to provide replacement parts and low cost mass storage peripherials, such as disk and tape units to accomodate the increase of over 1300 new users at the MFE Computer Center through this access program.

	FY 1984	FY 1985	FY 1986 Request
Engineering and Geosciences			
Operating Expenses	$18,915	$26,675	$26,675
Capital Equipment	1,150	1,500	1,500
Subtotal	$20,065	$28,175	$28,175

This subprogram funds the Department of Energy's principal long-range research efforts in the disciplines of mechanical engineering, electrical engineering, engineering physics, geology, geophysics and geochemistry. Projects are chosen for their scientific excellence and their long-term importance to meeting the Nation's energy needs.

In addition to the requests for operating funds discussed below, $1,500,000 is requested for capital equipment (examples: microprocessors and sensors for research on intelligent control systems at the Oak Ridge National Laboratory and imaging device equipment for geophysics studies at Pacific Northwest Laboratory) Experience has shown this is the minimum for capital equipment required for effective research in the areas covered by this subprogram.

Engineering Research

The Engineering Research part of this subprogram pursues two main goals: (1) to acquire a better understanding of basic phenomena and processes underlying current energy-related engineering practices, and (2) to expand the conceptual and technical base of engineering sciences to meet the needs of future energy technologies.

Broadly useful topics are chosen in areas of traditional engineering disciplines as well as in interdisciplinary areas, addressing problems related to energy production, distribution and utilization The following examples indicate the breadth of application of the topics being supported: (1) improved basic understanding of tribology, which covers friction, wear and lubrication, is pertinent to all energy generating and consuming systems with moving components; (2) the fundamental principles underlying the flow of multiphase fluids (mixtures of gaseous and liquid fluids) must be well understood to solve problems in petroleum and chemical industrial processes as well as in specific energy systems; e.g., geothermal, chemical, and solar; and (3) advanced instrumentation and equipment for use in extreme environmental conditions of high pressures, elevated temperatures and severe toxicity are needed for many energy technologies

Engineering Research has its focus on three areas: (1) Mechanical Sciences - including tribology, heat transfer, fluid mechanics, solid mechanics and structures; (2) Systems Sciences - including process control, large scale systems, machines in unstructured environments, and instrumentation; and (3) Engineering Data and Analysis - including nonlinear dynamics, and the development of critically needed data bases for energy engineering systems.

Recent accomplishments in Engineering Research include:

o A record high in operating temperature for a key type of solid state electronic device was achieved through improved fabrication methods; this paves the way to important advances for measurement methods and process control in hostile environments

o The identification of significant electro-chemical processes which induce wear in bearings, has provided the initial knowledge for finding suitable lubricant additives for wear reduction. Successfully completed and applied, this research should contribute to increased lifetime of generators, motors and pumps.

In FY 1986 $13,044,000 is requested for operating expenses, the same level as FY 1985, and will support carefully selected, generic, high quality engineering research in the existing program categories enumerated above. The collaborative work initiated in FY 1985 among universities, industry and national laboratories (primarily the Idaho National Engineering Laboratory and Oak Ridge National Laboratory) will be pursued in focused areas of research. The specific research areas to receive continued emphasis in FY 1986 include: advanced methods and processes (mainly research underlying plasma engineering and welding automation), intelligent machines in pseudo-structured and unstructured environments, basic research on multiphase flows, and advanced instrumentation research including the development of devices and sensors operable in hostile environments.

Geosciences

The evaluation, development and utilization of energy resources and the appropriate disposition of wastes from energy production are critically dependent upon our knowledge of the earth and its atmosphere. To meet the long-term needs of the Department for such science information, the Geosciences activity supports research which is germane to the Department's mission in geology, geophysics, inorganic and organic geochemistry, rock mechanics, thermodynamics, tectonics of geologic systems and solar-terrestrial physics. This research is carried out principally at the DOE National Laboratories and at U.S. universities. For example, coordinated research projects in Continental Scientific Drilling address long-range national energy concerns. Studies of the thermodynamic properties of rocks and migrating ground waters and of geochemical migration in the earth's crust are providing an improved data base for the design of waste repositories. Development of new geophysical methods and computer codes for modeling of geophysical data and their use in resource exploration and evaluation are leading to improved methods of locating energy resources, modeling the earth's crust and identifying sites for waste isolation.

Areas of emphasis and specific research projects are selected to increase our fundamental knowledge of processes relevant to the origin, detection and utilization of energy resources; problems of waste isolation in geologic media; and long-term solar wind and earth-climate variability. Specific Geosciences activities are currently focused on:

(1) Seismic, acoustic, electromagnetic and other geophysical methods of remote sensing in regions of high heat flow and energy resource potential.

(2) Drilling and associated geosciences activities specifically planned to increase fundamental knowledge of crustal structure and processes, with emphasis on the thermal regimes of the continental crust consistent with the Interagency Accord on Continental Scientific Drilling signed by DOE, NSF and the U.S. Geological Survey in April 1984.

(3) Rock mechanics, element migration, and energy and mass transfer in geological systems by means of laboratory experiments, computer simulation and field studies.

(4) Thermodynamic and kinetic studies of mineral and rock systems.

(5) Organic geochemistry investigations on the nature and origin of petroleum, natural gas and coal resources.

(6) The physics of the solar-terrestrial atmospheric interactions that affect the earth's present and future energy systems.

The Continental Scientific Drilling part of DOE's Geosciences Research has attracted substantial interest nationally and internationally (where major continental scientific drilling efforts are already underway). The portions dealing with thermal regimes are especially appropriate for support by the Department of Energy. The other cooperating agencies are NSF and USGS.

Recent Geosciences research accomplishments include the following:

o Continental Scientific Drilling at Long Valley, California. High heat flow and geothermal energy potential are often associated with silicic magma and volcanism. The first hole ever drilled completely through a recently cooled obsidian (silica-rich volcanic glass) lava flow was completed last November at Obsidian Dome, California. Core sampling recovery was close to 100 percent and subsequent analysis of the cores has revealed the surprising result that this lava flow, in spite of the nearly total absence of bubbles and a very high viscosity, had equilibrated fully with water vapor at a pressure of one atmosphere at, or very near, the earth's surface. This finding has been interpreted to mean that the magma approached the surface as a froth, rather than a viscous liquid, and was only later reconstituted as an essentially solid mass of glass by compaction while cooling in its final position. The outgassing characteristics of silicic magma as it approaches the surface are of paramount importance in assessing the distribution of available energy in a geothermal field as well as the potential danger of explosive volcanism.

o The Kinetics of Petroleum Formation. A combined field and laboratory study of the Green River shale in Utah provides direct geological verification of the rate of petroleum formation in nature. The shale contains kerogen (an oil precursor) where it is exposed at the surface on the edge of the Uinta synclinal basin. The same rock produces oil from depths of 12,000 - 16,000 feet inside the basin. By combining laboratory measurements of the state of compaction of shale samples recovered from drilling at successive depths with data on temperature versus depth, investigators have been able to reconstruct the time-temperature history of the Green River shale formation. For the oil producing zone, the average heating rate and maximum temperature achieved are 0.6x10E-9 degrees C/hr and 155 degrees C, respectively. This geologic reconstruction of the conditions of petroleum formation is in excellent agreement with laboratory experiments on the kinetics of the conversion of kerogen to petroleum which show a very pronounced rate maximum at 150 - 160 degrees C.

The FY 1986 request for operating expenses is $13,631,000, the same level as FY 1985, and will provide continuing support for the Department's Geosciences Research activities along lines for which the scientific priority is high and which bear directly on the long-range research needs of the Department. The thermal regimes portion of the cooperative interagency Continental Scientific Drilling Program (CSDP) will be maintained, consistent with the Interagency Accord cited above.

	FY 1984	FY 1985	FY 1986 Request
Advanced Energy Projects			
Operating Expenses..........................	$ 9,060	$ 10,602	$ 10,602
Capital Equipment...........................	310	320	320
Subtotal....................................	9,370	10,922	10,922

The objective of the Advanced Energy Projects subprogram is to explore the feasibility of novel, energy-related concepts, as they evolve from basic research. Such concepts are at an early stage of scientific definition and therefore would not qualify for support by technology programs. Because they are new and untried, those concepts invariably represent a high risk; to qualify for support they must also have the potential for an eventual high pay-off. Also supported is exploratory research on concepts that do not fit easily into the existing Department of Energy program structure. An area of major programmatic attention is the transfer of successful projects to proper technology programs; such transfers are effected every year.

Support of exploratory research on novel concepts is needed to provide the seed for technical innovation. However, such research does not generally qualify as basic research, where the objective is to gain knowledge and understanding of processes and phenomena in nature. Neither does it qualify as technology-related: the link with any specific technology needs yet to be established. Hence, the Advanced Energy Projects subprogram fills a very real void between basic and technology-related research.

Thus, for example, several novel approaches to controlled fusion--very different from those currently pursued--have been proposed as a result of basic research. One such approach, known as "muon-catalyzed fusion", evoked considerable interest and produced unexpectedly promising results; however, this research is still at too early a stage to determine if muon-catalyzed fusion can be considered a viable process for energy generation. The concept is actively being explored under Advanced Energy Projects sponsorship.

The mode of operation for this interdisciplinary subprogram is to support individual projects for a limited time only; it differs from other subprograms in that it does not fund ongoing evolutionary research. The spectrum of projects supported is very broad, encompassing, for example, the development of new sources of electromagnetic radiation, new methods of better fossil fuels utilization, totally new approaches to controlled fusion and new approaches to solar energy collection and utilization, to name a few. Close contact is maintained with DOE technology programs to ensure proper coordination. Projects are selected on the basis of unsolicited proposals received from researchers at universities, industrial laboratories (especially small R&D companies) and national laboratories. At present, about forty projects are being supported, which allows a turnover rate of about fourteen projects a year. A recent accomplishment of Advanced Energy Projects is the demonstration, for the first time, of a new source of electromagnetic radiation known as the free electron laser (FEL) at conversion efficiencies and power levels making FEL a candidate source for numerous applications, including extremely powerful accelerators.

Last year continued to bring evidence of a wide recognition of the Advanced Energy Projects subprogram as an important vehicle in promoting science-based technical innovation:

- o The annual Energy Technology Conference and Exposition held in Washington, D.C. in February 1983, devoted a special session to the BES Advanced Energy Projects subprogram. Speakers at the session were Principal Investigators on projects supported by this subprogram.
- o An article describing the Advanced Energy Projects subprogram appeared in Spectrum, a highly regarded journal of the Institute of Electrical and Electronic Engineers.

The FY 1986 request for the Advanced Energy Projects subprogram is $10,602,000 in operating expenses and $320,000 in capital equipment funds, the same as in FY 1985. By maintaining last year's level of project support, each project currently being funded will be required to absorb cost of living increases. The budget request will, therefore, maintain the total number of projects supported at last year's level of about forty; with a typical turnover period of three years. In addition, the subprogram will continue, on a modest scale, last year's initiative in exploring novel sources of electromagnetic radiation such as x-ray and gamma-ray lasers and electron lasers. Also, modest support for the muon catalyzed fusion effort is also envisioned.

	FY 1984	FY 1985	FY 1986 Request
Biological Energy Research			
Operating Expenses...........................	$ 10,534	$ 12,455	$ 12,455
Capital Equipment...........................	400	560	560
Subtotal..................................	10,934	13,015	13,015

The Biological Energy Research (BER) subprogram aims at generating results and information about fundamental biological mechanisms that will serve to underpin new and improved biotechnologies relating to energy production. The program focuses on botanical and microbiological areas, each roughly funded at the same level. The research is concerned with biological energy conversion mechanisms and their regulation and also how organisms use and conserve the energy available to them. Research on: photosynthesis, the major energy supply mechanism for living organisms; growth and development as a reflection of the strategy of how plants manage to trap and store energy; stress physiology as a means of determining how plants cope with water, salt and temperature insults and manage to carry out energy trapping; genetic mechanisms which represent improved means by which one may ultimately fashion "novel" plants as more efficient producers of the energy storage materials of interest, regulatory mechanisms of metabolic and morphological processes that are to be the targets for future genetic engineering; and plant-microbial interactions that are of critical importance to plant productivity and to losses of productivity in the case of pathogen attack. Of growing importance is work on the structure and function of plant cell walls that represent the largest renewable energy storage resource.

The microbiological segment of the program consists of projects investigating how microorganisms convert various materials to fuels and chemicals of interest. The main area of research is the underlying mechanisms of a number of fermentations and other conversions. Of special interest are the pathways of degradation of the major biological polymers in which energy is stored, namely, the polysaccharides, cellulose and hemicellulose, and the aromatic polymers of lignin. Special attention is given to understanding the enzymes involved, how their synthesis and activity is controlled and what the options might be for genetically regulating them. The process of methanogenesis is being defined with respect to the organisms involved (this is a process in which several types of anaerobic microbes must interact to make the whole process go), the interactive relationships and the control mechanisms imposed and the genetics of methanogens which has been virtually totally neglected until recently. Other conversions in which one carbon compound such as carbon monoxide and formaldehyde are converted to more desirable and industrially useful products also are studied. Thermophilic organisms, or those capable of growth at high temperatures, are being investigated for their usefulness in conversions by virtue of their higher conversion rates and decreased susceptibility to contaminations. The genetics of other potentially useful microorganisms for conversions also are being studied since essentially no genetics is known for most of these. Some studies on the fundamental biochemistry and genetics of organisms that produce surfactants useful in enhanced oil recovery also are being carried out.

The majority (over 72 percent) of these research funds are expended in university laboratories with a lesser amount in national labs (22 percent). The overall program is addressing critical questions whose answers will be the foundation of an industry employing biosystems to carry out a variety of conversions for fuel and chemical production. The work in this area is moving extremely rapidly and if the U.S. is to maintain its competitive position it is essential to take advantage of the rapid unfolding of information by pursuing the extremely promising leads promptly. Of particular importance is that both the plant sciences and fermentation microbiology (pharmaceutically related are the exception) have been relatively neglected for the past few decades. Both areas are now in a renaissance with an accompanying series of new discoveries.

At the FY 1986 requested funding level, the majority of committed projects in plant and microbial sciences would be continued. There will be terminations, however, to provide for inflation for high priority projects and to permit initiation of a few exceptionally meritorious new projects.

	FY 1984	FY 1985	FY 1986 Request
Program Direction			
Operating Expenses..........................	$ 3,518	$ 3,765 a/	$ 4,100
Total FTE's.................................	61	63	63

a/ Reflects savings of $65,000 for Section 2901 of the Deficit Reduction Act of 1984 (P.L. 98-369).

The FY 1986 request for Basic Energy Sciences Program Direction is $4,100,000, an increase of $335,000 over the FY 1985 level. These funds are required to provide for the personnel costs associated with 63 full-time equivalents. The additional funds will provide for within-grade and merit increases, and other increased costs associated with management of this program.

Basic Energy Sciences is a broadly diversified program responsible for mission-oriented research, the chief purpose of which is to provide the fundamental scientific and engineering base on which the Nation's future energy options depend. Its staff must possess expertise covering many subfields in the areas of chemistry, physics, engineering, metallurgy, geosciences, mathematics, and biology, as well as in administration, procurement and financial management. The staff is responsible for development, direction, and management of complex technical programs, each involving one or more of the scientific areas mentioned above. Their activities include assessing scientific needs and priorities of the program, planning to meet those needs, technical review of proposals from laboratories and universities, and monitoring the progress of ongoing university contracts, laboratory programs, and construction projects, as well as responding to the many day-to-day requirements involving budget, procurement and other management activities.

The research effort involved in the Basic Energy Sciences program is extremely diverse. In FY 1985, for example, approximately 1,200 research projects will be underway either at the Department's laboratories or at more than 150 colleges and universities in 45 states. Evaluation, monitoring and management of this large number of diverse projects primarily from the Headquarters requires frequent contact with the contractors and laboratory staff and involves numerous workshops, planning meetings, and project and program reviews throughout the year.

During recent years the number of research projects at universities with industry and not-for-profits has increased from 18 to nearly 30 percent of the BES budget, and the workload per offsite project is significantly greater than that for a laboratory project. This is especially true with regard to evaluation of proposals, of which approximately 10 percent of those reviewed result in new contracts each year. The requested staffing level is required to maintain a strong core program; to evaluate research programs which have continued to grow in recent years, especially in newer emerging priority areas having great potential importance to energy; to oversee management, operation, and ongoing construction of unique research facilities; and to promote early application of the results of this basic research.

In addition to the ongoing basic research program, all three phases of the Congressionally mandated SBIR program (Public Law 97-219) will be operating concurrently in FY 1986. Phase I was implemented in FY 1983; 9,000 solicitations were mailed, resulting in 1,734 proposals spread among 25 technical topics. There were 106 contracts awarded totaling over $5,000,000. The first year of operation resulted in much heavier than anticipated workload requiring extensive use of overtime and diversion of other scientific and administrative staff from their regular duties to assist in the SBIR work. The workload in FY 1984 increased even further as 96 of the 106 initial contractors submitted proposals to enter Phase II of the program; 51 were selected. In addition, 844 proposals were received for the new Phase I awards and were reviewed and evaluated. During FY 1985 the initial FY 1983 projects will enter the second year of Phase II, FY 1984 projects will enter their first year of Phase II, and new Phase I projects will begin. FY 1986 will be the first year all three phases of the program will be in operation at the same time. This results in substantial increases in the numbers of proposals to be processed and evaluated for all phases, the procurements and projects to be monitored and evaluated, the site visits for those projects entering Phase II, and the debriefings requested by contractors not receiving awards.

This program also funds the Scientific Computing Staff which was established to manage responsibilities related to large-scale scientific computing. This staff manages two important activities related to large-scale scientific computing. They are: (1) providing access to large computers for the researchers supported by the scientific programs of the Office of Energy Research, and (2) supporting research in scientific computing necessary to meet the Department's long-range needs. Specific workload includes managing a number of research projects, including conducting peer reviews and evaluating proposals, performing economic and cost benefit studies and analyses of user needs, managing the Magnetic Fusion Energy Computer Network, and providing a single DOE focal point to maintain liaison with other Federal agencies, universities, and concerned organizations.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
BASIC ENERGY SCIENCES

(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: General plant projects

2. Project No.: 86-R-400

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 2nd Qtr. FY 1986

4. Date construction ends: 4th Qtr. FY 1987

5. Previous cost estimate: None
Date:

6. Current cost estimate: $4,030
Date: 8/84

7. Financial Schedule:

		Costs			
Fiscal Year	Obligations	FY 1984	FY 1985	FY 1986	After FY 1986
Prior Year Projects	$ 300	$ 226	$ 0	$ 0	$ 0
FY 1984 Projects	400	150	250	0	0
FY 1985 Projects	3,750	0	1,350	2,400	0
FY 1986 Projects	4,030	0	0	1,000	3,030

8. Brief Physical Description of Project

This project is required to provide for minor new construction, other capital alterations and additions, and for buildings and utility systems. Where applicable, the request also includes the cost of installed capital equipment integral to a subproject. Funding of this type is essential for maintaining the productivity and usefulness of Department-owned facilities. Since it is difficult to detail this type of project in advance, a continuing evaluation of requirements and priorities may be expected to result in additions, deletions, and changes in the currently planned subproject. In general, the estimated funding for each location is preliminary in nature, and is intended primarily to indicate the relative magnitude of the requirements. No significant R&D program is anticipated as a prerequisite for design and construction of the subprojects under construction.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects	2. Project No.: 86-R-400

8. Brief Physical Description of Project (continued)

The currently estimated distribution of FY 1986 funds by office is as follows:

Argonne National Laboratory	$ 3,000
Ames Laboratory	600
Notre Dame Radiation Laboratory	30
Sandia National Laboratory	300
Stanford Synchrotron Radiation Laboratory	100
Total project cost	$ 4,030

9. Purpose, Justification of Need for, and Scope of Project

The following are examples of the major items to be performed at the various locations. Since needs and priorities may change, other projects may be substituted for the examples listed below, and some of these may be located on non-Government owned property.

Argonne National Laboratory.. $ 3,000

Group I - Plant Rehabilitation and Upgrade Projects - ANL-West

*1. Replacement Condensate Piping from SM-2 to Bldg. 774
2. Roof Reconstruction, Bldgs. T-6, T-12, and T-13
3. Rehabilitate Industrial Waste and Drainage Ditches
*4. Replace Indicator Valves
5. Rigging Test Addition, Bldg. 752, ANL-West

*General Site-Wide Support Facility. All others are programmatic support.

Group II - Plant Rehabilitation and Upgrade Projects - ANL-East

1. Cooling Tower Rehabilitation, Bldgs. 200, 203
*2. Replace Underground Vault Switches, Bldg. 211
3. Replace Exhaust System, Wing A, Bldg. 203
4. Modify Chilled Water Piping, Bldg. 203
*5. Rehabilitate Canal Water Pump Station Bldg. 582

*General Site-Wide Support Facility. All others are programmatic support.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects 2. Project No.: 86-R-400

9. Purpose, Justification of Need for, and Scope of Project (continued)

Group III - Programmatic Projects

1. Thermochemical Properties Laboratory, Bldg. 205
2. Fast Neutron Generator Target Area Expansion, Bldg. 314
3. AGHCF Shield Window Refurbishment, Bldg. 212
4. Helium Gas Recovery and Storage System, Bldg. 203
5. HFEF/S Fixed Air Sampling System, ANL-West

Of the total request of $3,000,000 for GPP at the Argonne National Laboratory approximately 50 percent will be used for plant rehabilitation and approximately 50 percent will be used for upgrading and programmatic projects. By group of project the split for FY 1986 will be about $500,000 for Group I projects, $2,000,000 for Group II, and $500,000 for Group III.

At present, a total documented GPP backlog of approximately $20,000,000 exists at ANL for required upgrading and programmatic projects at both sites. This backlog is not static and is constantly under review by ANL management so that the most critical requirements are taken care of as promptly as possible with available GPP funding. These requirements may come about as the result of the unscheduled failure of major plant components or the need to satisfy scientific program requirements.

The backlog of GPP projects has tended to increase steadily in recent years due to the shortfall in funding line item requests for plant rehabilitation at ANL-East and ANL-West, and because of programmatic shifts at ANL which have required modifications to the existing plant. When it is considered that total GPP funds available to ANL in FY 1983 and FY 1984 total only $2,100,000, it is readily apparent that while FY 1985 funding was increased ANL needs still far outpace the availability of funds with which to satisfy them.

Ames Laboratory.. $ 600

Requirements include for example: development building second floor addition, campus warehouse roof replacement, metallurgy building electrical system upgrade, water system upgrade and miscellaneous proejcts. The projects described will be constructed on the Ames Laboratory, non-Government owned property.

Notre Dame Radiation Laboratory... $ 30

Requirements include minor building modifications to properly house staff members and to make optimum use of laboratory research space. The projects described will be constructed on the Notre Dame Radiation Laboratory, non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects   2. Project No.: 86-R-400

9. Purpose, Justification of Need for, and Scope of Project (continued)

Sandia National Laboratory.. $ 300

Requirements include minor laboratory modifications required in support of the Combustion Research Facility. The conversion of light duty laboratory space to heavy duty laboratory space is an example of the type of project to be supported.

Stanford Synchrotron Radiation Laboratory.. $ 100

Requirements include minor modifications and additions necessary to support the optimum use of the laboratory research space.

10. Details of Cost Estimate

See description, item 8. The estimated costs are preliminary and, in general indicate the magnitude of each program. These costs included engineering, design, construction and inspection.

11. Method of Performance

Design will be on the basis of negotiated architect-engineer contracts. To the extent feasible, construction and procurement will be accomplished by firm fixed-price contracts and subcontracts awarded on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
BASIC ENERGY SCIENCES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No.: 86-R-401

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 1st Qtr. FY 1986

4. Date construction ends: 4th Qtr. FY 1987

5. Previous cost estimate: None
Less amount for CP&D: None
Net cost estimate: None
Date: 8/84

6. Current cost estimate: $2,995
Less amount for CP&D: 0
Net cost estimate: $2,995

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1986	$ 2,995	$ 2,995	$ 2,995	$ 1,500
1987	0	0	0	1,495

8. Brief Physical Description of Project

This project provides for additions and modifications to accelerator and reactor facilities, which are supported by the Basic Energy Sciences program. Since program priorities and needs change, the projects described below indicate the most likely projects to be funded. A continuing evaluation, however, is necessary to ensure that those projects with the greatest productivity are funded. Two projects at the Brookhaven National Laboratory are requested to incorporate improvements at the High Flux Beam Reactor and the National Synchrotron Light Source and two projects are requested at the Oak Ridge National Laboratory for improvements at the High Flux Isotope Reactor.

9. Purpose, Justification of Need for, and Scope of Project

The following are the projected items of work to be performed at the various locations. Since needs and priorities may change, other projects may be substituted for the examples listed below, and some of these may be located on non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations   2. Project No.: 86-R-401

9. Purpose, Justification of Need for, and Scope of Project (continued)

Brookhaven National Laboratory

High Flux Beam Reactor Facility (HFBR).. $ 180

Funds are requested for seismic instrumentation, fuel element cutting systems and fuel handling blower system improvements.

National Synchrotron Light Source (NSLS).. $ 1,615

Funds requested for the NSLS facility which consists of two electron storage rings, and electron linac and booster and which all require some annual improvements and modifications. Included in the request are: x-ray ring high density magnetic quadrupole coils, improvements to the VUV and x-ray ring radiofrequency systems, a 50 MHz booster folded cavity for 800 MeV operation, and improvements for increased energy capability of the linac injector.

Oak Ridge National Laboratory

High Flux Isotope Reactor (HFIR)... $ 1,200

These funds requested for the HFIR are needed for two purposes. The first is replacement of two heating exchangers which are corroding and nearing the end of their reliable lives; they are, of course, absolutely necessary to the operation of HFIR in a safe and efficient manner, since they provide for cooling of the water in the primary loop of the reactor. Two of the total four of HFIR's heat exchangers are being replaced in FY 1985, and with the other two in FY 1986 many more years of safe operation are assured. The second purpose is installing a remote sampling system within the reactor building, which would be needed in the event of a release of radioactivity. Although this is an unlikely event, safety considerations now dictate having such sampling available.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No.: 86-R-401

10. Details of Cost Estimate

a.	High Flux Beam Reactor Facility	$ 180
b.	National Synchrotron Light Source	1,615
c.	High Flux Isotope Reactor	1,200
	Total Project Cost	$ 2,995

11. Method of Performance

Design, engineering, and inspection will be performed by laboratory staff. To the extent feasible, construction and procurement will be accomplished by fixed-price subcontracts awarded on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
BASIC ENERGY SCIENCES
(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: Kansas State University, Ion Collision Physics Facility, Manhattan, Kansas

2. Project No.: 85-ER-403

---

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 2nd Qtr. FY 1985

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: $3,400

6. Current cost estimate: $5,100

Date: 8/84

---

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1985	$ 2,000	$ 2,000	$ 2,000	$ 1,500
1986	1,900	1,900	1,900	1,000
1987	1,200	1,200	1,200	2,100
1988	0	0	0	500

Financial schedule is based on the net Government funding associated with this project. The State of Kansas will provide an additional $1,000,000 for the conventional construction necessary to house the new capabilities.

8. Brief Physical Description of Project

The James R. MacDonald Laboratory will be expanded to house a new booster accelerator and a new low energy highly charged ion source. A 9,000 square foot basement addition will be required to house these facilities. The additional power requirement is 100 KVW. Very little additional water for cooling will be required.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Kansas State University, Ion Collision Physics Facility, Manhattan, Kansas   2. Project No.: 85-ER-403

8. Brief Physical Description of Project (continued)

New equipment to be installed in new basement addition includes:

A. Cryogenic ion source including electron gun, superconducting solenoid magnet. Analyzing magnet, accelerating column and beam line apparatus.

B. Superconducting linear accelerator includes resonators, amplifiers, power supplies, RF control system, superconducting solenoids, liquid nitrogen system, liquid helium refrigerator and storage dewar, accelerator control computer system, data acquisition and data reduction computer system.

9. Purpose, Justification of Need for, and Scope of Project

The construction of the ion collision physics facility, together with the existing atomic physics capability at Kansas State University, will constitute the Institute for Atomic Collision Physics. The project will involve construction and installation of (1) an advanced source of low energy highly charged ions of the CRYEBIS type and (2) a LINAC booster comprising twelve superconducting split-ring resonators. Each of these two additions will function as an adjunct to the existing tandem Van de Graaff in ways that, along with a dedicated system for high speed computation and data analysis, will have the capability to study the atomic physics of a spectrum of ions, energies and intensities unmatched in the world. This will open new areas of atomic collision physics, allow long beam time experiments, and provide a forefront environment for training young scientists and encouraging interdisciplinary cross-fertilization.

The total estimated cost for the project has been revised upward from the amount in the FY 1985 budget. The reestimate results from a more complete design, firm data on outside procurements, and a complete review of all components necessary for the scope of the project.

This project will be constructed on the Kansas State University campus, non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Kansas State University, Ion Collision Physics Facility, Manhattan, Kansas

2. Project No.: 85-ER-403

---

10. Details of Cost Estimate	Item Cost	Total Cost
a. Engineering, design and installation		$ 980
b. Land and level rights		0
c. Construction costs		330
1) beam line construction	$ 315	
2) utilities	15	
3) buildings	a/	
d. Equipment		2,900
e. Contingency		890
Total Project Cost		$ 5,100 a/

11. Method of Performance

This type of construction is unique and therefore the conceptual design, final design, assembly, and testing will be done by the staff of Kansas State University. Component parts equipment and building construction will to the extent possible be based on fixed priced competitively obtained procurement actions.

---

a/ Kansas State University will provide additional funding to construct the building. a) Estimate is based on completed conceptual design; b) Escalation is based on annual 8% to the mid-point of construction

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Kansas State University, Ion Collision Physics Facility, Manhattan, Kansas

2. Project No.: 85-ER-403

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	FY 1985	FY 1986	FY 1987	FY 1988	Total
a. Total project funding					
(1) Total facility costs					
(a) Construction line item	$ 1,500	$ 1,000	$ 2,100	$ 500	$ 5,100 a/
(b) CP&D	0	0	0	0	0
(c) Expense funded equipment	0	0	0	0	0
(d) Inventories	0	0	0	0	0
Total facility costs	$ 1,500	$ 1,000	$ 2,100	$ 500	$ 5,100 a/
(2) Other project funding					
(a) R&D necessary to complete construction	$ 180	$ 180	$ 50	$ 0	$ 410
(b) Other	0	0	0	0	0
Total other project funding	180	180	50	0	410
Total project funding	$ 1,680	$ 1,180	$ 2,150	$ 500	$ 5,510 b/

b. Related annual funding requirements (estimated life of project: 20 years)

(1) Operating costs	$ 0
(2) Programmatic operating expenses	600
(3) Capital equipment not related to construction but related to the programmatic effort in the facility	50
(4) GPP or other construction related to programmatic effort in the facility	0
(5) Other costs	0
Total	$ 650

13. Narrative Explanation of Total Project Funding and Other Related Requirements

No narrative required.

---

a/ Kansas State University will provide additional funding to construct the building. a) Estimate is based on completed conceptual design; b) Escalation is based on annual 8% to the mid-point of construction

b/ As noted above, the State of Kansas will provide an additional $1,000,000 for conventional construction of housing.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
BASIC ENERGY SCIENCES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

3. Date A-E work initiated: 1st Qtr. FY 1984

3a. Date physical construction starts: 2nd Qtr., FY 1984

4. Date construction ends: 4th Qtr., FY 1987

5. Previous cost estimate: $19,700

6. Current cost estimate: $ 19,700
Less FY 1983 PE&D: 0
$ 19,700

Date: 8/84

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1984	$ 2,500	$ 2,500	$ 2,500	$ 1,396
1985	10,000	10,000	10,000	10,254
1986	7,200	7,200	7,200	6,800
1987	0	0	0	1,250

Work included for accomplishment with the first year's appropriation of $2,500,000 will include but not be limited to the design and engineering of beam line components and preliminary and detail design of the support area construction.

8. Brief Physical Description of Project

Current program planning anticipates the need for the insertion devices (wigglers and undulators) and beam lines (front and end beam transport and experimental stations) to the existing VUV and X-ray rings. Design, fabrication and construction of up to three insertion devices and six beam lines is presently anticipated with the final configuration to be dictated by programmatic demands and the state of the art at the time of construction.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

8. Brief Physical Description of Project (continued)

The project also provides for design and construction of building space to house technical work areas, laboratories and offices and provide additional experimental staging and support areas.

A. New Experimental Equipment

This project provides for an expansion of experimental capabilities which will be made available to general users from university, industrial, national and government laboratories. The greatest use is anticipated to be by materials scientists, but sizeable participation is expected by chemists, biologists and other disciplines.

The new equipment to be provided will take maximum advantage of the properties of the NSLS source. As noted above the exact design of this equipment will be determined as the project progresses to maintain the flexibility necessary to develop state of the art facilities which will ensure high quality research capabilities. Four beam lines and associated insertion devices have been designated. Up to two additional beam lines may be constructed as dictated by science and permitted by available resources.

B. New Building Addition

The proposed addition to the NSLS building will provide elementary support and staging areas, laboratories, technical work areas and offices to promote more effective utilization of the NSLS facility. The technical staff will move to new work areas, making more space available for the new beam lines. Extending the experimental space adjacent to portions of the VUV and X-ray storage rings will allow a number of long beam lines to be constructed, permit additional branching of existing ports, and give some extremely useful space to users for specialized support equipment.

The proposed building expansion will add approximately 52,000 square feet of new space in a two-story addition to the north and east sides of the existing building.

The ground floor includes expanded experimental areas for x-ray and VUV, an angiography suite, laboratories, offices, technical work areas, a receiving and gas storage area, expanded lobby, mechanical equipment rooms and several public rooms. A tunnel connecting the ground floor to technical work space in an adjacent facility will be provided. First floor gross area is 28,912 square feet.

The second floor includes offices, technical work space, a large design room, a conference room and a mechanical room. Second floor gross area is 22,919 square feet.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

8. Brief Physical Description of Project (continued)

The expanded building will be designed to current DOE energy conservation standards and contain fire protection systems. Access by handicapped persons will be provided.

C. Existing Facility

The NSLS consists of two electron storage rings, an injection system common to both, experimental beam lines, experimental equipment, and office and support area all of which is housed in a 74,000 square foot building.

The high energy x-ray storage ring provides for the possibility of 28 primary beam ports, each of which is capable of accommodating several experimental beam lines. The VUV ring provides for 16 beam ports which are also capable of accommodating several experiments each. In sum, more than 90 experiments can be carried out at one time when the facility is fully instrumented. In addition to general users, research groups called Participating Research Teams (PRT's) from universities, industry and national and government laboratories, upon advice by a program committee, and approval by the NSLS Department Chairman provide instruments to carry out research programs at the NSLS facility. Their instruments are made available to general users for 25% of the available time. At present such groups provide an additional 20 experiments at the facility. General users are able to use any of the experimental lines, PRT or community lines, upon approval of their experimental proposal.

The NSLS is operated as a user facility. This means that researchers from BNL and other laboratories will be able, after review of a proposal by a committee of distinguished scientists, and acceptance by the NSLS Department Chairman to carry out an experiment using either the UV or X-ray radiation produced by the rings.

9. Purpose, Justification of Need for, and Scope of Project

The response from users, both within BNL and outside, has placed a demand on the NSLS facility far surpassing its present resources. The limited beam lines combined with the limited space available makes expansion of experimental research within the present confines of this facility unpracticable. In order to support further development of this facility it will be necessary to provide additional floor, laboratory, and staging space. An experimenter should have a choice of a wide range of instruments which he can utilize for this research. To provide this choice, two types of instruments are proposed:

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

9. Purpose, Justification of Need for, and Scope of Project (continued)

a) A group of instruments that will be available to general users that will complement in capability those already provided, and;

b) Several instruments (wiggler magnets and an undulator) which will provide a range of wavelength and intensity not available at the bending magnets. These instruments will be used both by general users and by members of the Participating Research Teams who will require such capabilities for their experiments.

A. New Experimental Equipment

In the original development plan, provision was made for a total of eight beam lines to be available to general users. Additional beam lines were to be provided at the rate of about two a year out of capital funds. Further instrumentation was to be made available by Participating Research Teams (PRT's), who would install beam lines at the rings at their expense and who would make 25% of the experimental time on those lines available to general users. However, the growth in user participation has far exceeded earlier expectations.

In order to provide experimental capabilities required both by PRT's and by general users, it is proposed to accelerate beam line construction. It is particularly important that the capabilities provided for in this project, such as wiggler magnets, be made available at the earliest possible date.

In addition to satisfying the requirements of the users, the accelerated design and construction of these beam lines will provide a cost saving because of efficiencies in planning, design, and construction.

B. New Building

The design for the NSLS building emphasized long term space requirements for the accelerator/storage rings and the equipment associated with their control and operation. Adequate space for experimental beam lines around the VUV and X-ray storage rings was also provided, although future long beam lines that extended beyond the building walls were regarded as a possible future option.

The space for the machine and experiments was given highest priority in initial design, while support areas were provided to satisfy requirements for projected use during the initial years of operation. A possible expansion of experimental support areas, work areas, and offices was allowed as a future option. Therefore, only minimal space was given to several general laboratories, the second floor office-administration area, and other support areas.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project:	Beam lines and support area construction National Synchrotron Light Source (NSLS) Brookhaven National Laboratory, Upton, NY	2. Project No.: 84-ER-111

9. Purpose, Justification of Need for, and Scope of Project (continued)

It was projected that during the early years of operations, up to approximately 50% of the 28 X-ray and 16 UV ports would be utilized. The extremely enthusiastic response of the scientific community now forces us to advance the expected rate of beam line construction and building expansion. More than 20 experiments have been proposed by PRT's, which are expected to be constructed at an early date. This response, coupled with the beam lines to provide by the project, indicate that the experimental floor would be extremely crowded beyond October 1983 and additional support space would be essential.

The original design anticipated a possible need for future expansion. The building frame was designed to support a third floor over the office administration wing. Site utility lines were kept at least 30 feet from the building foundation. Adequate space was left between the NSLS buildings and the Safety and Environmental protection building.

In addition to the pressing need to return experimental floor space to its intended use, the expansion will provide adequate office space for the permanent staff and work areas to complement the research and development associated with the anticipated experimental and machine improvement programs. The short connecting tunnel between the NSLS building and the basement of the adjacent Instrumentation building will connect the NSLS staging areas to an area where now extensive NSLS vacuum, instrument, and diagnostic work is in progress and where UV and X-ray test sources are located.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

9. Purpose, Justification of Need for, and Scope of Project (continued)

Annual Costs

The estimated incremental operating costs of the proposed NSLS beam lines and support area construction are listed below. Costs are in FY 1986 dollars.

	(Dollars in Thousands)
Materials, Supplies, Support Services	$108
Electric Power	181
General and Administrative	46
Total	$335

10. Detail of Cost Estimate a/b/

	Item Cost	Total Cost
a. Engineering, design and inspection, including A-E fee (approx. 25% of item c)..	$	$ 3,305
b. Land and land rights		0
c. Construction costs		13,465
(1) Beam line construction	6,430	
(2) Sitework	85	
(3) Structures	6,455	
(4) Facility Modification	495	
d. Standard equipment		770
Subtotal		17,540
e. Contingency		2,160
Total project cost		$ 19,700

---

a/ Estimate is based on a 90% Title II design.

b/ Escalation rates conform to the guidelines prescribed in the Department of Energy Field Budget Process Chapter, August 1984, which are based on the materials and labor data contained in the Energy Supply Planning Model and escalation rates forecasted by Data Resources, Incorporated (DRI). Current costs have been escalated by 5.6%, 4.9%, 6.4% and 6.7% per year on beam line construction for FY 1984 through FY 1987, and 6.4%, 5.4% and 4.6% on conventional construction for FY 1983 through FY 1985.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

11. Method of Performance

Insertion device and beamline construction is unique and therefore the conceptual design, final design, assembly and testing will be done by the staff of the National Synchrotron Light Source of the Brookhaven National Laboratory. Component parts wherever possible will be fabricated by industry under fixed priced competitively obtained procurement actions. Some components may be fabricated in the existing shops at BNL. It is also anticipated that other laboratories, private consultants, and industrial firms will be used for advice on specific problems. Building design will be on the basis of a negotiated architect-engineer contract and its construction will be by a competitively obtained lump sum contract which may be phased.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1984	FY 1985	FY 1986	FY 1987	Total
a. Total project costs						
1. Total facility costs						
(a) Construction line item.........	$ 0	$ 1,396	$ 10,254	$ 6,800	$ 1,250	$ 19,700
(b) CP&D...........................	0	0	0	0	0	0
(c) Expense Funded Equipment.......	0	0	0	0	0	0
(d) Inventories....................	0	0	100	100	0	200
Total facility costs...........	0	1,396	10,354	6,900	1,250	19,900
2. Other project costs						
(a) R&D necessary to complete construction of beam lines.....	900	500	500	0	0	1,900
(b) Other..........................	0	0	0	0	0	0
Total other project funding....	900	500	500	0	0	1,900
Total project funding..........	$ 900	$ 1,896	$ 10,854	$ 6,900	$ 1,250	$ 21,800

CONSTRUCTION PROJECT DATA SHEETS .

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

12. Funding Schedule of Project Funding and Other Related Funding Requirements (continued)

b. Total related funding requirement (estimated life of project: 17 years)

1. Operating costs	$ 355
2. Programmatic operating expenses directly related to the facility	0
3. Capital equipment not related to construction but related to the programmatic effort	0
4. GPP or other construction related to the programmatic effort	0
5. Other costs	0
Total other related annual funding requirements	$ 355

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project funding
  1. Total Facility
    (a) Construction line item - no narrative required.
    (b) CP&D - no narrative required.
    (c) Expense funded equipment - no narrative required.
    (d) Inventories - it is anticipated that funds will be required for the procurement of special process spares.
  2. Other project funding
    (a) R&D necessary to complete construction - funds provided in the NSLS R&D budget. This item gives estimates of the R&D necessary to develop the monochromators, mirror systems, target chambers, detectors and superconducting structures for high field wigglers and undulators.
    (b) Other - no narrative' required.

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: Beam lines and support area construction
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory, Upton, NY

2. Project No.: 84-ER-111

---

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements (continued)

b. Total related funding requirements

1. Operating Costs - There will be an annual requirement of additional materials, supplies, and support services associated with the new beam lines. Also, there will be a requirement for increased facility electrical power.
2. Programmatic operating expenses directly related to the facility - no narrative required.
3. Capital equipment not related to construction but related to the programmatic effort - no narrative required.
4. GPP or other construction related to the programmatic effort - no narrative required.
5. Other costs - no narrative required.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
BASIC ENERGY SCIENCES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Center for Advanced Materials, Lawrence Berkeley Laboratory, Berkeley, California

2. Project No.: 84-ER-112

3. Date A-E work initiated: 3rd Qtr. FY 1984

3a. Date physical construction starts: 4th Qtr. FY 1984

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: $ 40,250

6. Current cost estimate: $ 40,450
Less FY 1984 PE&D: 200
$ 40,250
Date: 8/84

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1984	$ 1,760	$ 1,760	$ 1,760	$ 437
1985	10,790	10,790	10,790	5,423
1986	17,440	17,440	17,440	10,875
1987	9,060	9,060	9,060	12,840
1988	1,200	1,200	1,200	10,675

8. Brief Physical Description of Project

The Center for Advanced Materials (CAM) is comprised of two research laboratories. This is a continuation of the FY 1984 request, Center for Advanced Materials (CAM), and which takes into consideration the recommendations of the ad hoc review Panel.

The Research Laboratories will involve two new laboratory complexes at LBL, the Surface Science and Catalysis Laboratory (SSCL) and the Advanced Materials Laboratory (AML).

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Center for Advanced Materials
Lawrence Berkeley Laboratory, Berkeley,
California

2. Project No.: 84-ER-112

8. Brief Physical Description of Project (continued)

The CAM facilities at LBL will be located on University of California property adjacent to the Berkeley campus, within the site of the Lawrence Berkeley Laboratory. The project will include the construction of new facilities, and the alteration of, and additions to, existing facilities. Plant and site facilities will consist of: a) improvements to land, including grading, drainage, paving, lighting, and walkways; b) a new Surface Science and Catalysis Laboratory (SSCL) building (approximately 47,000 GSF), located near the existing Materials and Molecular Sciences Laboratory (Building 62); c) the new approximately 80,000 GSF building, the Advanced Materials Laboratory (AML); d) the extension of existing utilities, including electrical power, water, sewage, gas, and communications; and e) standard equipment and special facilities including office and laboratory furniture and equipment, fume hoods, ventilation and temperature control equipment, laboratory diagnostics and instrumentation equipment, fire protection equipment and computation equipment.

The Surface Science and Catalysis Laboratory will be located near the existing Materials and Molecular Sciences Laboratory (Building 62). The 3-story building will have a reinforced-concrete frame, shear walls, waffle roof-and-floor structure supported on spread footings. Auditorium and administrative area roofs will utilize metal deck on steel framing. The floor plan is approximately 95 x 150 feet.

The Advanced Materials Laboratory will consist of a single light-laboratory building. The proposed four-story building will occupy a hillside site providing a first floor with a main entrance at the grade level of the base of the hill. The full floor-plan will be L-shaped, about 192 feet long in one direction and 173 feet in the other; the longer element will be 63 feet wide and the other, 96 feet wide. The building structure will consist of a reinforced concrete frame with shear walls. Roof and floors above the base level will be of waffle-slab construction. Foundations will consist of poured-in-place reinforced concrete caissons.

Finishes on the new buildings will include: standard built-up roofing over insulation; exterior (non-bearing) walls of prefinished panels on metal studs (insulated cavity); and gypsum board interior wall surfaces throughout. Acoustical ceilings will be needed in certain areas; otherwise ceilings will be painted gypsum board. Laboratory furniture and fume hoods will be commercial products with acid/alkali-resistant tops and construction. Building elevators will be rated for 6000 lb. capacity, suitable for carrying freight and passengers. Heating ventilating and air conditioning (HVAC) needs will be met by central station air-handling units, draw-through cooling coils, return fan units and economizer controls. All supply and return air will be ducted. All buildings will be equipped with automatic fire sprinkler and alarm systems. Utilities will be extended from nearby existing plant services.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Center for Advanced Materials
Lawrence Berkeley Laboratory, Berkeley,
California

2. Project No.: 84-ER-112

9. Purpose, Justification of Need for, and Scope of Project

This research center is being proposed as a major scientific redirection of the Lawrence Berkeley Laboratory to address a vital national need, to accelerate basic research in an area that promises medium-term impact on high-technology industries, and to foster closer ties between national laboratory researchers and their counterparts in industrial and university laboratories. The CAM project will have two major objectives:

- To enhance understanding, through long-range basic research, of the synthesis, characterization, and properties of advanced materials in support of U.S. energy-related and high-technology industry.
- To provide advanced facilities for research training of additional graduate students in physical sciences and engineering fields vital to U.S. high-technology industry.

The CAM project will provide the modern tools and facilities required for making possible major advances in energy-related and high-technology industries by improving the scientific understanding of the underlying chemical and physical phenomena that influence both materials and device behavior.

Two research laboratories form the major components of the CAM:

- The Surface Science and Catalysis Laboratory (SSCL). A laboratory devoted to surface and catalysis studies using state-of-the-art instrumentation techniques.
- The Advanced Materials Laboratory (AML). A laboratory devoted to interdisciplinary study of the synthesis and characterization of energy-related, high-technology, and strategic materials. In addition, there will be research on the design of high-technology devices utilizing new materials and the design of innovative devices for the characterization of materials-property relationships.

Both the SSCL and the AML will be based on strong programs that already exist at LBL. Other elements are completely new, but they too build on experience and personnel already at LBL and at the adjacent University of California Berkeley campus. The first CAM research program associated with the above was initiated in FY 1984.

Because of the pressing need to retain high-technology leadership, the proposed project schedule calls for the start of construction in FY 1984 and the completion of all facilities in FY 1988. Delays would extend the time at which research results can be generated and transferred to U.S. industry. A CAM Advisory Board composed of scientific leaders from industry, universities, and Federal laboratories will advise the LBL director on CAM scientific program

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Center for Advanced Materials
Lawrence Berkeley Laboratory, Berkeley,
California

2. Project No.: 84-ER-112

9. Purpose, Justification of Need for, and Scope of Project (continued)

directions to ensure that CAM basic research addresses America's long-range high-technology needs. The CAM affiliates, consisting of major research teams from industry and universities, will participate in CAM. The following cost estimates and mix among facilities may vary depending upon the research and development progress, but does represent the current plan.

This project will be constructed at the Lawrence Berkeley Laboratory which is non-Government owned property.

10. Details of Cost Estimate

	Item Cost	Total Cost
a. Engineering, design, inspection and administration	4,840	
b. Construction costs	22,930	
c. Standard equipment	5,850	
d. Removals and relocations	260	
e. Contingencies at approximately 19% of above	6,370	
Total estimated cost		$40,250

11. Method of Performance

Conventional facilities engineering design will be performed under a negotiated Architect/Engineer subcontract. Inspection and some engineering will be done by Laboratory personnel. Construction and procurement will be accomplished by fixed-price subcontracts awarded on the basis of competitive bids.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Center for Advanced Materials
Lawrence Berkeley Laboratory, Berkeley,
California

2. Project No.: 84-ER-112

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988	Total
a. Total facility construction costs: a/						
SSCL	$ 437	$ 4,483	$ 6,745	$ 285	$ 0	$11,950
AML	0	940	4,130	12,555	10,675	28,300
Total facility construction cost	437	5,423	10,875	12,840	10,675	40,250
Total Project Funding	$ 437	$ 5,423	$10,875	$12,840	$10,675	$40,250

b. Other related funding requirements (estimated life of project: 25 years)

	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988	FY 1989
1. Programmatic research	$ 2,300	$ 2,900	$ 3,700	$ 6,200	$10,500	$15,500
2. Capital equipment related to programmatic research	1,300	600	1,200	2,000	2,200	2,400
Total	$ 3,600	$ 3,500	$ 4,900	$ 8,200	$12,700	$17,900

---

a/ Includes escalation to midpoint of construction for all conventional facilities and compounded annually for special facilities; FY 1985 6.2%; FY 1986 6.5%; FY 1987 $6.3%; FY 1988 6.6%; FY 1989 6.8%.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Center for Advanced Materials
Lawrence Berkeley Laboratory, Berkeley,
California

2. Project No.: 84-ER-112

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project funding

(1) The major elements of the CAM facility have been described in Item 8. The funding profiles were determined as follows:

(a) The Surface Science and Catalysis Laboratory has a completed Title II design. Construction will be packaged with site preparation planned in FY 1984 so that building construction can be completed in the second quarter of FY 1987.

(b) The Advanced Materials Laboratory building is scheduled for Title I review in the fourth quarter of FY 1985. The project will be scheduled to sequence bid packages to minimize disruption to existing programs and construction congestion and to optimize favorable bidding conditions and work leveling. Site bid packages will be let in the second quarter of FY 1986. Building construction will begin in the first quarter of FY 1987 and end in the fourth quarter of FY 1988.

b. Other related funding requirements

The annual costs of the scientific program are increased progressively to build up a high quality research staff for the CAM laboratories. Funding in the early years of the project is mainly to attract superior senior scientists to lead the new scientific programs described in Item 9. These researchers can be housed initially on the University campus and then in the SSCL Building until all conventional facilities are completed. The programs will expand in the latter years of the project to include the full complement of scientists and technicians. The capital equipment needs related to this research staff buildup reflect Laboratory experience that numerous laboratory equipment items will be needed at the level of approximately 20% of the operating program budget. These amounts were augmented in the first two years to take into account startup capital equipment needs.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
BASIC ENERGY SCIENCES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Stanford Synchrotron Radiation Laboratory Enhancement
Stanford Linear Accelerator Center
Stanford, California

2. Project No.: 84-ER-113

3. Date A-E work initiated: 1st Qtr. FY 1984

3a. Date physical construction starts: 2nd Qtr. FY 1984

4. Date construction ends: 4th Qtr. FY 1986

5. Previous cost estimate: $12,930

6. Current cost estimate: $13,330
Less FY 1983/1984 PE&D: 400
$12,930

Date: 8/84

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1984	$ 1,240	$ 1,240	$ 1,240	$ 544
1985	9,130	9,130	9,130	6,261
1986	2,560	2,560	2,560	6,125

8. Brief Physical Description of Project

The Stanford Synchrotron Radiation Laboratory (SSRL) Enhancement will be located at the Stanford Synchrotron Radiation Laboratory. SSRL is colocated with the Stanford Linear Accelerator Center (SLAC) on Stanford University property that has been leased to the Department of Energy.

The SSRL Enhancement project will include the construction of new conventional and research facilities and the alteration of and additions to existing facilities for the purpose of providing ultra-high brightness synchrotron radiation from insertion devices (wigglers and undulators).

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Synchrotron Radiation Laboratory Enhancement
Stanford Linear Accelerator Center
Stanford, California

2. Project No.: 84-ER-113

8. Brief Physical Description of Project (continued)

The project is divided into three major portions: (a) construction of two beam lines, one on the SLAC Positron Electron Project (PEP) storage ring and one on the SLAC SPEAR storage ring; (b) alteration of the electron storage ring SPEAR for high flux synchrotron radiation research and (c) construction of three conventional facilities: a PEP Beam Line Facility (PBF) (3,100 GSF), a Light Assembly Shop (LAS) (8,600 GSF), and a Laboratory/Office Building (LOB) (26,200 GSF).

SSRL Conventional Construction

The site at PEP chosen for the PEP Beam Line and the associated facility -- (PBF) is just within the existing SLAC lease boundary and it will not be necessary to acquire more land from the University for the facility. The site requires a retaining wall for the access road, service yard, and PBF building which will be half buried into the PEP ring earth shielding mount. The PBF will be an experimental hall with three adjoining rooms and partial mezzanine. The Light Assembly Shop (LAS) will consist of a Vacuum Clean Room, and Vacuum Shop Office, a Beam Line Component Assembly Shop, a small Machine and Welding Shop, a Machine Shop Office, a Beam Line Component Storage Deck, and support rooms. The Laboratory/Office Building (LOB) will be a two story building. The upper floor will provide up to 43 offices, a library, a conference room, a drafting room, a lounge-kitchen area; seven work rooms and two HVAC equipment rooms. The ground floor will provide a receptionist area, two large work rooms, up to 24 offices, an x-ray lab, a metrology lab, a VUV lab, an electronics lab and four lab storerooms.

The optimum location for the LOB is presently occupied by an existing SLAC liquid hydrogen storage facility which SSRL will relocate to a new site selected by SLAC.

Special Facilities

A 26-period, 2-meter rare-earth cobalt undulator magnet will be installed on the PEP storage ring to produce photon beams peaked at 13 KeV. A scattering beam line will originate with a 54-pole rare-earth cobalt wiggler magnet on the spear storage ring. Machine improvements will include reduction of SPEAR emittance and vertical aperture, beam stabilization, and a new LINAC electron injection system.

9. Purpose, Justification of Need for, and Scope of Project

Over the past decade, the development of synchrotron radiation has led to major advances in a number of different scientific and technological fields, but particularly materials science, condensed matter physics and chemistry, as

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Synchrotron Radiation Laboratory Enhancement
Stanford Linear Accelerator Center
Stanford, California

2. Project No.: 84-ER-113

9. Purpose, Justification of Need for, and Scope of Project (continued)

well as the biological sciences. Each order of magnitude increase in photon flux or spectral brilliance achieved during this period has resulted in qualitatively new experiments which provide previously unobtained information and yield new understandings.

The most significant recent advances in photon flux and brilliance have been, or will be, the result of: (a) the development of insertion devices (wigglers and undulators) at SSRL and (b) improvements in storage ring characteristics (reduction of emittance and increases in current).

As a result, new storage rings are presently being planned which are optimized for high spectral brilliance and photon flux through utilization of insertion devices, rather than bending magnets, for the production of radiation and through the achievement of extremely low emittances and high currents. These rings are also optimized for specific spectral regions through choice of stored electron energies. Generally, stored electron energies at 1.0 to 1.5 GeV are utilized for ultra-high brilliance soft x-ray and vacuum ultraviolet (VUV) generation whereas rings of greater than 3.0 GeV are used for ultra-high brilliance x-ray generation.

The SSRL improvements described here will rapidly and economically yield major increases in the photon flux and spectral brilliance available at SSRL in all spectral ranges. In addition, x-ray spectral brilliance far beyond those achieved or proposed elsewhere in the world will be obtained. The SSRL construction will also increase the time available for dedicated synchrotron radiation operation of the storage ring SPEAR and increase the effectiveness of utilization of the radiation. At the same time, it will provide for testing and development of individual insertion devices as well as the techniques for utilizing many insertion devices on one storage ring.

The existing Stanford Synchrotron Radiation Laboratory has outstanding user facilities that can be dramatically and quickly improved in the hard x-ray region, thereby providing researchers with unparalleled photon brightness over an extended portion of the electromagnetic spectrum. A past 100-fold improvement to SSRL intensity in the soft x-ray region involved the installation at SPEAR of a permanent magnet undulator conceived and built at LBL. A current LBL/SSRL collaboration will provide a 50-fold improvement over the entire energy range based on an LBL-developed wiggler. Therefore, it is logical to continue joint activities to further improve SSRL facilities as a cost-effective way of providing researchers with additional advanced tools to complement those available elsewhere.

This project will be constructed at the Stanford Linear Accelerator Center which is non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: Stanford Synchrotron Radiation Laboratory Enhancement
Stanford Linear Accelerator Center
Stanford, California

2. Project No.: 84-ER-113

---

10. Details of Cost Estimate

	Item Cost	Total Cost
(a) Engineering, design, and inspection..................	1,630	
(b) Construction costs....................................	8,070	
(c) Standard equipment....................................	520	
(d) Removals and relocations..............................	100	
(e) Contingencies at approximately 19% of above..........	2,610	
Total estimated costs..		$ 12,930

11. Method of Performance

The SSRL special facilities engineering design will be done by Laboratory (SSRL and SLAC) personnel, as will major technical component construction and assembly. Technical component construction and fabrication will be done by a combination of SLAC shops and by subcontracts awarded on the basis of competitive bidding and managed by SSRL and SLAC personnel.

Conventional facilities engineering design will be performed partially under a negotiated Architect/Engineer subcontract, but primarily by the SLAC Plant Engineering Dept. on a "best efforts" basis. Inspection and some engineering will be done by Laboratory personnel. Construction and procurement will be accomplished by fixed-price subcontracts awarded on the basis of competitive bids.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Synchrotron Radiation Laboratory Enhancement
Stanford Linear Accelerator Center
Stanford, California

2. Project No.: 84-ER-113

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	FY 1984	FY 1985	FY 1986	Total
a. Total facility construction costs: a/				
SSRL Enhancement	$ 544	$ 6,261	$ 6,125	$ 12,930
Total facility construction cost..........	544	6,261	6,125	12,930
b. Other project funding:				
SSRL R&D..................................	800	700	0	1,500
Total R&D/Startup.........................	800	700	0	1,500
Total Project Funding.....................	$ 1,344	$ 6,961	$ 6,125	$ 14,430

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project funding

(1) The major elements of the SSRL Enhancement have been described in Item 8. The funding profiles were determined as follows:

(a) At SSRL the PEP Beam Line will be accomplished during the first two years. Improvements to SPEAR are scheduled for the second year and the Laboratory Office Building is scheduled for the second and third

---

a/ Includes escalation to midpoint of construction for all conventional facilities and compounded annually for special facilities; FY 1984 N/A; FY 1985 6.2%; and FY 1986 $6.5%.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Synchrotron Radiation Laboratory Enhancement
Stanford Linear Accelerator Center
Stanford, California

2. Project No.: 84-ER-113

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements (continued)

years. Completion of the SPEAR scattering Beam Line and the Laboratory-Office Building will occur during the third year.

(2) Other project funding

(a) Insertion Devices and Beam Line Optical Elements R&D activities include in-vacuum undulators, and advance beam line components suitable for ultra high brilliance photon beams.

(b) SSRL R&D is related in support of the construction project includes prototype development and R&D on technical components.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
ENERGY RESEARCH ANALYSIS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT

(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
Energy Research Analysis				
Operating Expenses	$ 2,766	$ 3,000	$ 3,000	$ 2,700

Authorization: Section 209, P.L. 95-91

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF CHANGES
ENERGY SUPPLY RESEARCH AND DEVELOPMENT

(In thousands of dollars)

1985 Appropriation enacted	$ 3,000
Program increases and decreases:	
- Program restraint of 10% proposed as part of the Government-wide deficit reduction program	- 300
1986 budget request	$ 2,700

Energy Research Analysis

The Energy Research Analysis (ERA) program provides DOE with the capability for independent, objective analysis of the Department's technical needs and opportunities. ERA fulfills the responsibility of the Director, Office of Energy Research, "to monitor the Department's Energy R&D programs in order to advise the Secretary with respect to any undesirable duplication or gaps in such program," Section 209(b)(2), Public Law 95-91. In addition, funding and staff are required to support technical assessment and coordination needs within the increased interagency research relating to acid rain.

The ERA program is conducted by the Office of Program Analysis (OPA) and is the only Departmental program specifically designed to provide independent technical assessments of other programs. A principal task of ERA is to solicit and obtain credible judgments by premier researchers and expert scientists of the quality of DOE science and its eventual impact. Another task which often follows from these judgments is the determination of the priority of different research efforts. These prioritized research needs provide the future directions for DOE program managers based on the views of the very best researchers in their area. This method of technical review has evolved over the past 4 years, involving several hundred industry, academic and laboratory researchers.

The overall ERA FY 1986 objectives provide for: (1) one to two independent analyses of DOE R&D programs to evaluate technical merit and future directions; (2) two to three assessments of technologies; (3) support for assessment and coordination elements within the National Acid Precipitation Assessment Program, including support for the Interagency Acid Deposition Assessments Staff and DOE's share of the Program Coordination Office support; (4) support of groups such as the Energy Research Advisory Board (ERAB) and JASON, and (5) technical support on issue papers and alternative action studies, and assisting in international representation of United States Energy R&D policies to the International Energy Agency (IEA).

The budget request for FY 1986 includes the necessary support for planned assessments of the National acid precipitation research program which has grown from $18 million in FY 1983 to about $60 million in FY 1985. Assessments of all of the avenues being investigated in acid precipitation (or acid rain) are extremely important to provide prompt and informed guidance and changes in direction, if necessary. ERA supports program reviews and extensive coordination of acid precipitation research, fulfilling the key role in such liaison as a result of the consortium role mandated by Congress for the DOE laboratories. Acid rain research is funded by many agencies; however, assessment of the research is supported only by the Environmental Protection Agency (EPA) and the Department of Energy (DOE).

RECENT ACCOMPLISHMENTS

o Program assessments completed during FY 1984 and FY 1985 which involve peer review of current research by panels of experts followed by determination of future research needs and priorities include the following:

  - An assessment of research needs in the Advanced Research and Technology Development Program (AR&TD) requested by the Assistant Secretary for Fossil Energy. AR&TD accounts for about 20 percent of the total Fossil Energy FY 1985 budget. Several significant program direction changes resulted from this assessment of over 100 projects by 10 panels of experts. For example, several gasification projects were either restructured or terminated. Project management in liquefaction has been changed in some instances, and the materials program is also reorienting several projects.

  - An assessment of the need for continuation of the High Altitude Sampling Program in the Office of Health and Environmental Research.

o Technology assessments are usually performed by panels of experts who investigate current research by various methods. These panels are similar to those in program assessments. However, several individual investigators may be used and their reports consolidated to cover the full area of the technology as an alternative approach. A large number of technology assessments have been completed recently (FY 1984 or FY 1985), including assessments of:

- Research needs in drilling, for both oil and gas, describing the need for a Federal role for long term objectives;
- Research needs in photovoltaics, which primarily recommended that materials and advanced concepts research should concentrate on silicon materials;
- Research needs in high level radioactive waste; investigations into the performance of spent fuel as a waste form during storage, transportation and emplacement was its first recommendation;
- Geoscience-related research needs for geothermal energy technology identified Federal research needs in four areas, but placed reservoir engineering objectives as the first priority;
- Research needs for the solar thermal technologies identified degradation mechanisms (materials), optics (thermal science) and photochemical reactions (thermochemistry) as areas most appropriate for support;
- Research needs in large-scale systems which identified the development of simultaneous, real time solution techniques of parallel models using supercomputers as its highest long term research priority.
- Research needs for Fuel Cell Research. This technology assessment was performed similar to a program assessment except that the panel of experts toured the primary research and engineering facilities at industry and university sites interviewing key researchers.
- Research needs in exploring the continental crust through drilling. An international symposium highlighted the primary research needs for exploring the earth's continental crust and arrived at a statement of international cooperation which was supported by all participants.

o Acid Precipitation

ERA continues to represent DOE on the Interagency Task Force on Acid Precipitation (ITFAP) which plans, coordinates, assesses and establishes the budgets for all Federal acid rain research. The ERA effort during FY 1986 will be to continue to support the assessment and coordination activities.

A recent OPA-sponsored report by JASON identified a key scientific uncertainty in atmospheric chemistry: whether a reduction in emissions of SO_2 and NO_x would result in a like, or much smaller proportional, reduction in acid deposition on sensitive areas. ERA has been instrumental in bringing research to bear on this issue and the National Laboratory Consortium will be heavily involved in a comprehensive multi-year research effort by FY 1986 to resolve this question.

The Operational Research Plan of the National Acid Precipitation Assessment Program (NAPAP) calls for early views on the research efforts across all task areas by FY 1986; assessments supported by ERA will provide the core of these views. This work is performed by the Acid Deposition Assessment Staff which is a group of EPA and DOE employees organized through a Memorandum of Understanding between the two agencies in 1982.

The NAPAP 1983 Annual Report to the President and Congress theme chapter was prepared by ERA with the assistance of leading acid rain scientists. This chapter showed the extent to which acid rain science has changed over the past year.

- Studies which are directed at more specific or limited objectives than program or technical assessments:
  - JASON studies which are performed by a DOD/DOE expert group of physicists to explore topics of mutual interest and direct attention to future research needs. Recent studies included atmospheric chemistry (acid rain), microwave physics, Advanced Isotope Separation Technology, tunable lasers and third generation weapons;
  - Lessons learned regarding technology transfer in the battery program, explored current battery research and pointed toward the most useful future direction;
  - An analysis of selected solar hydrogen and electricity production systems compared five solar systems and their potential for research;
  - The Foreign Applied Sciences Assessment Center study topics included: catalysis, low-energy lasers, combustion science and pattern recognition mathematics;
  - Studies performed in-house by OPA staff included:
    - An analysis of the lessons learned in the development and deployment of six technologies requested by the International Energy Agency (IEA);
    - Comparative data and analysis for the annual IEA/CRD survey of United States R&D funding;
    - Developing suggestions and priorities for cooperative research projects for the United States and Israel;
    - Developing advice on a review of proposals for cooperative research with Mexico; and
    - Commentaries and other input for the IEA Energy Technology Systems Analysis Project.
- Other tasks performed by OPA for the Department included:
  - Preparation of the Department's contribution to the Annual Science and Technology Report to Congress;
  - Compilation and analysis of cost sharing agreements;
  - Commentary on Fossil Energy's study, "Tool to Estimate the Maturity of Energy Systems;"
  - Representing the Department on the following Intra- and Interagency Committees:
    - The Subcommittee on Atmospheric Research in the Committee on Atmospheric and Oceans, chaired by the National Science Foundation;
    - Landsat (program terminated)
  - A study of Technology Transfer, its characteristics and how it is undertaken by the various outlay programs and office within DOE.

PROJECTED ACTIVITIES

- o Assessments:
  - One to two program assessments to examine the quality and impact of current research and to determine research needs for future directions are planned. These will include programs such as Geothermal Energy and Building Energy Systems Research.
  - Two to three technology assessments are planned for the coming year; technologies to be examined include: Low Level Waste from Commercial Nuclear Power Reactors, Nonhighway Transportation, and Semiconductors for Photovoltaic Applications.
- o Acid Precipitation
  - The assessment function for acid precipitation is the largest single assessment activity funded by ERA. As mentioned earlier, much of the early research across all acid precipitation tasks will begin to provide results by FY 1986 and the urgency of this National issue requires prompt review of these results.
- o Interagency and Departmental Liason:

  Another area of continuing responsibility for the office is the coordination and guidance of resolution of technical issues that require Departmental or interagency participation.

  - OPA will support the Director, Office of Energy Research, on reassessments of the Department's R&D priorities, programs and technology base and on interagency representations such as the Committee on Interagency Radiation Research and Policy Coordination.
- o Analyses of Research:
  - Comparison analyses of the recommendations of advisory groups versus actual research programs have been regularly requested in the past and will continue in FY 1986.
- o Advisory Groups:

  Advisory groups, such as ERAB, will continue to be supported for the Department at the direction of the Secretary.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
UNIVERSITY RESEARCH SUPPORT
SUPPORTING RESEARCH AND TECHNICAL ANALYSIS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - OPERATING EXPENSES
(Tabular dollars in thousands. Narrative material in whole dollars)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
University Research Support (ER)				
University/National Laboratory Cooperative Research				
University Laboratory Cooperative Research Operating Expenses..........	$ 3,467	$ 6,550	$ 6,550	$ 6,800
University Reactor Fuel Assistance Operating Expenses..........	1,500	3,892	3,892	1,900
	$ 4,967	$10,442	$10,442	$ 8,700
Energy Manpower Development				
Energy Manpower Assessment Operating Expenses..........	270	450	450	450
Energy Education and Training Operating Expenses..........	200	300	300	550
Subtotal..................	470	750	750	1,000
Total Operating Expenses..............	5,437	11,192	11,192	9,700
University Research Support.......	$ 5,437	$11,192[a][b]	$11,192[a][b]	$ 9,700

Authorization: Section 209, P.L. 95-91, Section 31, Atomic Energy Act of 1954, Section 103 (103), P.L. 93-483.

---

[a] FY 1985 amount does not reflect a reduction of $1,000,000 for IG Audit, prior year deobligation Management Initiative Savings.

[b] Reflects savings of $8,000 for Section 2901 of the Deficit Reduction Act of 1984 (P.L 98-369).

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF CHANGES
UNIVERSITY RESEARCH SUPPORT
(In thousands of dollars)

1985 Appropriation enacted	$ 11,192
1986 base	$ 11,192
Program increases and decreases:	
University Laboratory Cooperative Research	
o Increases support for student/faculty research and training appointments at the DOE laboratories	+ 250
University Reactor Fuel Assistance	
o Reduces funding associated with the conversion of university nuclear reactors to Low Enriched Uranium	- 1,992
Energy Manpower Assessment	
o None	0
Energy Education and Training	
o Provides support for 22 PREP awards and for high school science teacher workshops at DOE laboratories	+ 250
1986 budget request	$ 9,700

The principal goal of the University Research Support (URS) program is to help maintain strong scientific/technical research capabilities in support of the Department's long range energy R&D mission in both the university community and the national laboratories. This is accomplished through supporting specialized research and manpower development efforts which complement and underpin the R&D mission of other Departmental programs. The URS program provides a Departmental focus for several efforts which involve universities both directly or in conjunction with the Department's national laboratories and major contractors. Individual efforts carried out through the URS program therefore relate to one or more of the following mission objectives:

o Maintain and strengthen university-based energy research and manpower development efforts in selected high priority energy research fields.

o Utilize the unique resources of the national laboratories (equipment, instrumentation, and personnel) for university faculty and student research and training.

o Increase the number and enhance the quality of students, including women and minorities, pursuing professional-level degrees in energy-related science or engineering.

o Help strengthen the scientific/technical workforce in the Department's national laboratories.

URS-supported activities may be distinguished from other Department programs by their multidisciplinary nature and by their focus on manpower/development needs.

The URS program consists of two major subprograms. The first subprogram, University/National Laboratory Cooperative Research, is directed at strengthening the capabilities of both universities and national laboratories as major energy research performers in the conduct of long range energy research. Many of the activities supported within this subprogram involve joint efforts between university and laboratory-based researchers. The second subprogram, Energy Manpower Development, includes efforts to increase the number of students pursuing energy-related engineering and science careers. This subprogram also includes support for implementing the Department's statutory responsibility for assessing the supply and demand of manpower for both current and projected energy R&D programs.

In order to carry out URS program objectives, a variety of approaches are used including faculty research appointments, graduate and undergraduate student research participation in national laboratory programs, joint efforts involving laboratory and university scientists and support for the operation of unique university-based nuclear research and training reactors.

In FY 1985, the following major accomplishments are planned for the URS program.

o Increase the number of student research participants in the Laboratory/Cooperative Activities by 50 percent, reinstate the engineering faculty/students research teams at DOE laboratory sites, increase by 50 percent the number of high school science teachers participating in DOE research and training programs and initiate support for cost-shared visiting industrial research scientist appointments at DOE laboratories.

o Based on congressional requirements, initiate studies related to the conversion of selected university research and training reactors to the use of low enriched (20%) uranium fuel in place of the high enriched fuel (93%). Continue the university reactor sharing program at 18 to 20 universities.

- o Continue in-depth analyses of the supply/demand for manpower in energy R&D programs including publication of a comprehensive survey of manpower requirements in a number of energy R&D areas of direct relevance to the Department.

- o Support six high school teacher/student institutes in energy-related science and mathematics at the DOE laboratories and 20 Prefreshman Engineering Program projects designed to encourage women and minority high school students to select careers in science and engineering.

The URS program also supports numerous special research contracts in which costs are shared by the universities. The universities' contributions are provided by a number of mechanisms, e.g., salaries to investigators, summer student assignments, provision of facilities and/or equipment, etc. The URS program encourages such cost sharing policies to achieve maximum utilization of available Federal funds.

	1984	1985	1986 Request
University Research Support..............	$ 5,437	$11,192	$ 9,700

The FY 1986 request for the University Research Support Program is $9,700,000, a decrease of $1,492,000 from the amount available in FY 1985. Specific priorities at the requested level are as follows:

- o Support approximately 1,100 undergraduate student research appointments at the laboratories.

- o Refuel six university nuclear research reactors and support 20 reactor sharing projects.

- o Continue support for laboratory based high school teacher/student institutes and for joint research and manpower development efforts with Historically Black Colleges and Universities and for 22 Prefreshman Engineering Program projects reaching over 2,000 junior and senior high school students.

- o Continues cost-shared support for visiting industrial scientists through the joint DOE National Laboratory-Industry Technology Exchange Research Program.

The following sections describe the proposed activities which will be carried out at the FY 1986 request level within each of the major URS subprograms.

	1984	1985	1986 Request
University/National Laboratory Cooperative Research....................	$ 4,967	$10,442	$ 8,700

The major emphasis of this subprogram is to strengthen the capabilities of the national laboratories and universities and to conduct long range energy research and related manpower development.

University Laboratory Cooperative Research...............................	$ 3,467	$ 6,550	$ 6,800

This activity includes a variety of approaches which are designed to bring the DOE Laboratories and the universities into a closer partnership in meeting national priorities for energy research and manpower development. One of the principal

objectives is to maintain the flow of manpower for future energy research programs by involving students in ongoing laboratory research programs. Additional research capabilities are also available to the Department's Laboratories through participating faculty and their universities. Funding is provided to ten multi-program laboratories and university consortia (who work with other DOE contractors) for the placement of faculty, graduate, and undergraduate students in summer or academic year research and training activities.
The FY 1986 request includes support for the following:

o Undergraduate Student Research: Approximately 1,100 undergraduate science and engineering students will be supported in summer research assignments in the participating laboratories. Each student is assigned to an ongoing laboratory research program and is involved in energy related research significant to the Department's needs.

o Graduate Student Research: Graduate students who have completed their academic course work and are ready to undertake their thesis research are eligible for support under this program. About 230 graduate students in the sciences and engineering will collaborate with laboratory staff in areas of fundamental and applied research that are of direct interest to DOE.

o Faculty Research: About 200 faculty members from colleges and universities will participate in ongoing research at DOE laboratory and contractor sites. These appointments include both summer and academic year assignments. In a number of cases continued support is provided for on-campus research through funding provided directly by the laboratory's research programs.

o Special Energy R&D Training: Over 700 university faculty and students will participate in special energy-related workshops, short courses and institutes conducted at national laboratories on selected energy R&D topics and problem areas at the forefront of energy R&D. A sample of the workshops and institutes conducted in previous years within this activity are: Workshop on Small Angle Neutron Scattering, Experiments in Laser Spectroscopy, Separation of Proteins by Two-Dimensional Electrophoresis, and Energy Policy: Priorities and Future Goals.

o National Laboratory/Historically Black Colleges and Universities Programs: Continued support will be provided for cooperative research and manpower development programs between DOE laboratories and Black Colleges including ongoing efforts with Jackson State University/Lawrence Berkeley Laboratory and Atlanta University/Argonne National Laboratory.

o DOE/Industry Technology Exchange Program: The Department is committed to increasing the flow of energy-related scientific and technical concepts from the national laboratories to private industry. One of the most effective and proven mechanisms of technology transfer is the use of person-to-person interactions. Building on previous experiences and approaches in the University

Laboratory Cooperative Program, a joint laboratory-industry visiting scientist program was initiated in FY 1985. The purpose of this effort is to bring researchers from industrial laboratories to the Department's laboratories to participate in new or emerging energy R&D of mutual interest to DOE and industry. An oversight committee of DOE and industrial scientists provides overall guidance for this effort. Research projects and participants are selected by the participating laboratories and industries. Participants are supported by a research fellowship with some cost sharing for one year with an option for extension. Thirty research participants will be supported in FY 1986.

	1984	1985	1986 Request
University Reactor Fuel Assistance......	$ 1,500	$ 3,892	$ 1,900

This program provides fuel for university research and training reactors, particularly those higher powered reactors with Material Test Reactor (MTR) type fuel. The university-based nuclear research and manpower development effort is highly dependent on these specialized facilities not only for nuclear related training but also for research in the basic sciences. Some of the current uses are neutron physics, trace analysis and radiochemistry, primarily in the fields of human nutrition, health and geochemistry, nuclear materials such as structural alloys for fusion reactors, etc. Under the Reactor Sharing Activity, additional funding is provided to help defray reactor operational costs when the facility is "shared" with researchers from neighboring universities.

At the FY 1986 request level six to seven reactors will be refueled during FY 1986 and approximately twenty reactor sharing grants will be made on a competitive basis. Also, in the interest of efficiency and economies of production, efforts will continue in the development of a standard, low enriched uranium fuel plate for the MTR type reactors that are refueled annually.

	1984	1985	1986 Request
Energy Manpower Development.............	$ 470	$ 750	$ 1,000

This subprogram combines two manpower-oriented efforts -- Manpower Assessment conducts studies and analyses of the supply and demand of manpower for both current and future energy R&D programs, and the Energy Education and Training effort supports activities directed at encouraging secondary school students to pursue energy-related science and engineering programs at the college level.

Energy Manpower Assessment..............	$ 270	$ 450	$ 450

Under Section 103 (10) of the Energy Reorganization Act of 1974, the Department is required to assure "the collection, analysis, and dissemination of necessary manpower supply and demand data" to carry out energy-related programs. In responding to this mandate, the Manpower Assessment effort, in conjunction with other Federal agencies, develops and maintains information systems to provide both governmental and private sector managers with current and projected data on the supply and demand of energy-related scientific, engineering and technical manpower, at all occupational and degree levels, disaggregated to national, regional and state areas. This information enables public/private sector policy makers and planners to determine the specific manpower-related implications (on national and subnational levels) resulting from various energy technology options and developments.

In FY 1985, the Manpower Assessment effort completed its annual analysis of changing engineering, scientific and related manpower requirements and the supply implications of current and projected trends in energy R&D and energy production activities. The program completed its analyses of doctoral scientists and engineers in energy R&D and related programs of new science and engineering graduates who are involved in energy work upon entering the labor market.

The FY 1986 request of $450,000 will assure the continuation, analysis and dissemination of base line-type data on the employment, utilization and supply of scientists and engineers in developing varied energy sources and programs. This effort will include a new survey of nuclear-related occupational employment in private industry, government-owned contractor-operated facilities and government agencies to assess changing requirements caused by shifting emphasis among various segments of the nuclear energy field. Further, an evaluation of current and potential personnel supply for nuclear-related activities will be undertaken through a survey of the enrollees and graduates in nuclear engineering and health physics/-radiation protection. Support will also be provided to undertake the biennial survey of experienced scientists and engineers currently involved in energy work as well as of recent BS/MS science and engineering graduates to determine the extent of their participation in different energy technology developments.

	1984	1985	1986 Request
Energy Education and Training..........	$ 200	$ 300	$ 550

Engineers continue to be vital to the Nation's economic well-being and security, including energy. The Department's Prefreshman Engineering Program (PREP) is aimed at providing highly qualified minority and women engineers to help meet this national manpower requirement. PREP's career development emphasis is placed on minority and women junior/senior high students who are undecided regarding future academic careers. Over its 11-year history, two out of three PREP participants have selected engineering as the major course of study in college. This competitive program awards grants to engineering institutions to conduct summer enrichment programs on campus which includes such experiences as classwork in math and science, communications skills, computer applications, problem-solving exercises, and field trips to engineering industries. Each PREP award receives additional funding from local industries. Twenty-two PREP awards will be supported at the level requested in FY 1986 reaching over 2,000 students. The Department will also continue support for the DOE Special Awards Program at the International Science and Engineering Fair. Under this program, ten high school student winners and their science teachers receive a one-week visit to a national laboratory (the 1985 winners will visit the Lawrence Livermore National Laboratory). This award is a way of recognizing and encouraging scientific excellence among our Nation's precollege students.

As part of the Department's assistance in the national effort to improve the teaching of science and mathematics in secondary schools, support will be provided to special workshops and institutes at three national laboratories. These workshops/institutes are designed to utilize the capabilities of laboratory scientists in strengthening teacher skills in such essential energy-related areas as physics, chemistry and computer science. Individual projects will be planned and conducted with close involvement of teachers and administrators in school districts located near the participating laboratories.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
UNIVERSITY RESEARCH INSTRUMENTATION
Supporting Research and Technical Analysis
Energy Supply Research and Development - Operating Expenses

(Tabular dollars in thousands. Narrative material in whole dollars)

	FY 1984 Appropriation	FY 1985 Appropriation	1986 Base	1986 Request
University Research Instrumentation (ER) Operating Expenses.............	$3,976	$5,000	$5,000	$4,500
Total Operating Expenses.............	3,976	5,000	$5,000	4,500
University Research Instrumentation.............	$3,976	$5,000	$5,000	$4,500

Authorization: Section 209, P.L. 95-91

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF CHANGES
UNIVERSITY RESEARCH INSTRUMENTATION

(In thousands of dollars)

1985 Appropriation enacted..	$ 5,000
1986 base..	$ 5,000
Program increases and decreases:	
o Decreases the number of planned instrumentation awards from approximately 17 to 15 competitively selected awards..................	- 500
1986 budget request...	$ 4,500

The University Research Instrumentation Program provides support to university research groups on a competitive basis for the purchase of major, state-of-the-art scientific research instrumentation which is essential for continued progress in advanced energy-related scientific and technical research. Continued progress by university researchers in both fundamental energy research as well as research directed at improving current and developing new energy technologies requires direct access to new research instrumentation. For example, frontier-level research in surface science and catalysis requires the ability to describe what is occurring at the atomic and molecular level in order to understand such phenomena as carbon gasification, soot particle nucleation and growth and the composition of surface gases. Instruments used in this research must be able to detect and identify materials at the parts per billion level. In the field of biological energy research a major limitation is in understanding the key proteins which influence physiological and genetic factors related to plant productivity. For example, it is particularly difficult to determine the amino acid sequences of polypeptides; however, advances in the analytical capacity of mass spectrometry now offer biological scientists a means to overcome this problem.

Many university scientists do not have direct access to sophisticated, state-of-the-art scientific research instrumentation. This is a serious national problem being addressed through the combined efforts of Federal science agencies, state governments, private industry and by the university community itself. The Federal effort is coordinated by the Office of Science and Technology Policy through the Interagency Committee on University Research Instrumentation. Each participating Federal agency is responsible for supporting university research instrumentation in relation to agency missions and programmatic needs.

The Department's response to this overall national effort is the University Research Instrumentation Program initiated in FY 1984 to help support the purchase on a competitive basis by university researchers of state-of-the-art instrumentation costing in excess of $100,000.

In FY 1984, 17 awards were made, as a result of the competition, for instruments to support energy-related research in the following research areas: biological energy conversion, nuclear waste isolation, combustion, and multiphase and fluid flow phenomena. In FY 1985, it is anticipated that approximately 8 to 15 awards will be made for instrumentation in the following fields: catalysis, advanced materials characterization, biological energy conversion, geoscience and CO_2 research, process and systems dynamics and control and health and environmental impacts of energy-related chemicals.

	1984	1985	1986 Request
University Research Instrumentation.......	$ 3,976	$ 5,000	$ 4,500

The FY 1986 request for the University Research Instrumentation Program is $4,500,000 a decrease of $500,000 from the FY 1985 appropriation. This level will support an estimated 15 competitively selected awards for instrumentation costing over $100,000. As in prior years, the program will concentrate on those university research groups which have already demonstrated expertise in one of a small number of high priority energy-related topics which are of special concern to the Department's research programs. Among the topics to be considered in FY 1986 are catalysis, bioconversion, engineering research including materials, the geological sciences and environmental research. Each award will be cost-shared with the selected university.

The University Research Instrumentation Program remains complementary to but does not replace the Department's efforts to provide support for scientific equipment required on individual research projects supported through the various research programs.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
ADVISORY AND OVERSIGHT PROGRAM DIRECTION
ENERGY SUPPLY RESEARCH AND DEVELOPMENT
SUPPORTING RESEARCH AND TECHNICAL ANALYSIS

(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
Energy Oversight, Research Analysis and University Support				
Advisory and Oversight Program Direction				
Operating Expenses....	$ 3,400	$ 2,831	$ 2,831	$ 2,900
Total....................	3,400	2,831 [a]	2,831	2,900
Staffing Total FTE's.....	43	44	44	44

[a] Reflects savings of $69,000 for Section 2901 of the Deficit Reduction Act of 1984 (P.L. 98-369).

Authorization: Section 209, P.L. 95-91.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF CHANGES
ENERGY SUPPLY RESEARCH AND DEVELOPMENT

(In thousands of dollars)

1985 Appropriation enacted	$ 2,831
Program increases and decreases:	
Increased personnel costs	+171
Impact of the Presidentially proposed reduction for the 5% decrease in salaries and benefits	-102
1986 budget request	$ 2,900

Advisory and Oversight Program Direction

The FY 1986 Departmental Request for Advisory and Oversight Program Direction is $2,900,000, an increase of $69,000 above the FY 1985 level. These funds are required to provide for the personnel costs associated with 44 full-time equivalents in the Office of Field Operations Management, the Office of Program Analysis, the Science and Technology Affairs staff, and associated program and administrative support staff. The funding increase will provide for the increased costs associated with management of the program activities carried out by these organizations.

This program provides the personnel resources required by the Director of Energy Research to carry out his responsibilities under legislation (P.L. 95-91) and as mandated by the Secretary in areas beyond the scope of the other assigned Energy Research programs. This staff performs and supports in-house and external analyses and studies to meet ER's responsibilities for monitoring the Department's research and development programs and to advise the Secretary with respect to the well-being and management of the multiprogram laboratories. These responsibilities include advising on research activities carried out by any of the Assistant Secretaries; providing support for the Energy Research Advisory Board and the Laboratory Management Council; and providing program management of the Energy Research Analysis, University Research Support, Multiprogram General Purpose Facilities (MGPF), and the University Research Instrumentation programs.

The FY 1986 request supports the following staff activities:

1. The Office of Program Analysis will continue to support the Director, Office of Energy Research, in his role as the principal science advisor to the Secretary by providing technical assessments, independent peer reviews and program evaluations.

2. The university-laboratory research support and energy manpower development programs will continue to be supported. Increased workload resulting from implementation of Secretarial guidelines on expanded and improved DOE/university relationships will be absorbed at the current staffing level. The principal goal is to help maintain strong scientific/technical research capabilities in support of the Department's long-range energy R&D mission in both the university community and the national laboratories. This is accomplished through specialized research and manpower development efforts which complement and support the R&D mission of other Departmental programs. The University Research Support program provides a Departmental focus for several efforts which involve universities both directly or in conjunction with the national laboratories and major contractors.

3. For the University Research Instrumentation program, staff effort is required to perform such tasks as preparation of the program solicitation, analysis of proposals, selection of awards, and monitoring final implementation.

4. Department-wide laboratory management activities of the Office of Field Operations Management will continue with increased responsibilities. Oversight of DOE laboratory management will include provision of policy and management improvement recommendations and operation of the Department's institutional planning process. Participation on internal working groups and external Government-wide groups such as the OSTP Committee on Laboratory Management will continue as a significant demand for staff time. The staff will provide secretarial and analytic support for the recently established Laboratory Management Council in their review of issues relating to DOE laboratories. The staff will manage the implementation of a more effective laboratory appraisal process by the operations offices. ER institutional planning will be conducted for five national multiprogram energy laboratories and for the major single

purpose laboratories. The staff will also manage the MGPF program to revitalize the R&D facilities and the R&D Laboratory Technology Transfer program, which has an increasing workload.

5. The Energy Research Advisory Board will continue to be supported. Two new Departmental awards, similar to the Lawrence and Fermi Awards, have been proposed in the areas of conservation and renewable energy. A panel will be established for each of these new awards and the Science and Technology Affairs Staff will provide administrative support to the panels, as well as coordinate the entire awards process.

6. Program and administrative support in the areas of budget and finance, personnel administration, policy and coordination, and construction management support will continue to be provided within this program.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
MAJOR ACTIVITY OVERVIEW

Multiprogram Laboratories Facilities Support

The goal of the Multiprogram Laboratories Facilities Support (MLFS) program is to provide for the rehabilitation, upgrade, and replacement of multiprogram general purpose support facilities that are deteriorated, non-functional, overaged, overcrowded, inefficient or inadequate to meet security, environmental, safety and health requirements to the point that R&D program activities are impaired.

This program consists of two subprograms. The first subprogram, Multiprogram General Purpose Facilities (MGPF), originated in FY 1981 and is directed at the goals of the overall program except for environmental compliance needs at ORNL. The latter, Environmental Compliance (Oak Ridge National Laboratory), is a separate subprogram in FY 1986 and future budget years because of the magnitude of the requirements there. Each subprogram is discussed in detail in the following section.

Multiprogram general purpose support facilities are facilities which are suited for and utilized by many different programs where no one program uses more than approximately 60 percent of the facility. These include roads, railroads, site utilities, and support buildings such as laboratories, office buildings, shops, warehouses, etc.

The following facilities and sites are included in the program:

Ames Laboratory
Argonne National Laboratory (ANL)
Brookhaven National Laboratory (BNL)
Hanford Engineering Development Laboratory (HEDL)
Idaho National Engineering Laboratory (INEL)
Lawrence Berkeley Laboratory (LBL)
Lawrence Livermore National Laboratory (LLNL)
Los Alamos National Laboratory (LANL)
Oak Ridge National Laboratory (ORNL)
Pacific Northwest Laboratory (PNL)
Richland Operations (RL)
Sandia National Laboratories (SNL)

These sites received over $3,000,000,000 in FY 1984 to perform National research programs in nuclear energy, fusion energy, basic energy sciences, nuclear physics, high energy physics, life sciences, and other energy-related areas. Over 50,000 contract personnel are engaged in these activities. The productivity of the work force is highly dependent on adequate support facilities.

The replacement costs of the existing support facilities at the multiprogram sites exceeds $6,500,000,000. Through continuous use, aging and changing technology, these facilities deteriorate to a point where they are no longer appropriate for their intended functions, economically justifiable to maintain, or adequate to meet security, environmental, safety and health requirements. The MLFS program is responsible for keeping these support facilities adequate to ensure the continued effective accomplishment of the DOE's R&D missions today and in the future. The MLFS program is aimed at rehabilitating, upgrading and replacing inadequate facilities in a systematic and prioritized manner. The MLFS program is an appropriate Federal role reflecting the responsible management of the Government's real property.

The MGPF program in the period FY 1981 - FY 1985, has received $165,000,000 for rehabilitation, upgrade or replacement of deficient buildings, utilities, roads and railroads at the multiprogram laboratories.

In FY 1985, for example, the program will, in addition to continuing projects previously approved, initiate projects that:

- Replace roofs at ANL
- Upgrade environmental monitoring at ORNL
- Replace site fire alarm system at RL
- Repair Roads at LBL, INEL, RL and ANL
- Upgrade the Central Chilled Water Plant at ORNL
- Replace the Medical Facility at LLNL
- Construct a Central Chilled Water Facility at BNL
- Repair and Upgrade the Electrical Distribution System at ORNL
- Rehabilitate water and waste treatment systems at ANL

The specific objectives of the program from FY 1986 to FY 1990 will remain, as in the past, to rehabilitate and replace deficient facilities which are essential to the continued operations of multiprogram sites, and to prolong the life of the Government's large investment in real property facilities at these sites.

The Department is faced with an extensive environmental cleanup effort at Oak Ridge National Laboratory (ORNL). Over the years, ORNL has generated a variety of radioactive and nonradioactive pollutants; however, many of these pollutants were not considered hazardous by regulatory agencies until the Resource Conservation and Recovery Act (RCRA) regulations were promulgated. Other environmental laws and regulations passed in the last five years which have an impact on the present ORNL situation include the Safe Drinking Water Act, the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the Hazardous Materials Transportation Act. These new regulatory requirements in the Clean Water Act and the Clean Air Act, have resulted in the application of more stringent environmental criteria to ORNL operations. Long established procedures and approaches to handling hazardous wastes are no longer acceptable. Consequently, ORNL is presently in violation of a number of these laws. These violations were verified in part during a recent Evaluation Inspection of ORNL conducted by the State of Tennessee and the Environmental Protection Agency. The Department is currently working with these agencies to determine the actions necessary to correct these violations.

The Department is in the process of defining an environmental management plan that would ultimately bring ORNL into compliance with all applicable regulations. An initial plan for the entire Oak Ridge complex was submitted on February 19, 1984, to the Subcommittee of Energy, Research and Production of the House Science and Technology Committee. From this initial plan, a separate plan for ORNL was developed; however, additional technical assessments are necessary before definitive cost estimates can be provided. In FY 1985, the Department proposes to reprogram $5,400,000 to identify and measure environmental problems, determine their potential environmental impact, and determine what preventative and corrective measures need to be taken. The Environmental Compliance (ORNL) subprogram will, in FY 1986, continue to correct and identify the deficiencies at ORNL.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
ENERGY SUPPLY RESEARCH AND DEVELOPMENT
(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
Multiprogram Laboratories Facilities Support (ER)				
Multiprogram General Purpose Facilities				
Construction...........	$ 42,100	$ 33,200	$ 33,200	$ 29,300
Subtotal MGPF..........	$ 42,100	$ 33,200	$ 33,200	$ 29,300
Environmental Compliance (ORNL)				
Operating Expenses.....	$ 0	$ 0[a]	$ 0[a]	$ 12,900
Capital Equipment......	0	0	0	1,000
Construction...........	0	0	0	8,000
Total Environmental Compliance.........	$ 0	$ 0	$ 0	$ 21,900
Total				
Operating Expenses.....	$ 0	$ 0	$ 0	$ 12,900
Capital Equipment......	0	0	0	1,000
Construction...........	42,100	33,200	33,200	37,300
Multiprogram Laboratories Facilities Support........	$ 42,100	$ 33,200	$ 33,200	$ 51,200

Authorization: Section 647, Public Law 95-91.

---

[a] Pending approval of a reprogramming request, $5,400,000 will be devoted to this activity in FY 1985.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF CHANGES
ENERGY SUPPLY RESEARCH AND DEVELOPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
(In thousands of dollars)

1985 Appropriation enacted	$ 33,200
Built in increases and decreases:	
1986 base	33,200
Program increases and decreases:	
Multiprogram General Purpose Facilities	
o Slow down four on-going FY 1985 projects	- 4,400
o Add one new project for fire-protection improvements at BNL	+ 500
Subtotal	$- 3,900
Environmental Compliance ORNL	
o Initiate activities to correct environmental problems at ORNL	+ 12,900
o Equipment to support cleanup activities	+ 1,000
o Non-radiological process waste treatment project	+ 3,000
o General Plant Project	+ 5,000
Subtotal	$+ 21,900
1986 budget request	$ 51,200

	FY 1984	FY 1985	FY 1986 Request
Multiprogram Laboratories Facilities Support.........	$ 42,100	$ 33,200	$ 51,200
Multiprogram General Purpose Facilities (Construction)..	42,100	33,200	29,300

The MGPF program was established in FY 1981 to respond to the large backlog of facility support projects needed to maintain the adequacy of MGPF in fulfilling mission responsibilities. An overall backlog of $1,300,000,000 was quantified through a comprehensive inventory and assessment of all facilities at multiprogram sites in FY 1981. Each facility was surveyed and evaluated by experienced facility managers at the sites and deficiencies were identified, categorized and evaluated. Required minimum standards covering condition, capacity, location, safety and other factors were utilized to determine the extent of deficiencies. The consolidated results were reviewed and approved by field organization personnel and submitted to Headquarters.

The inventory identified 17,000,000 square feet of laboratory/office space and 9,000,000 square feet of other support buildings such as shops, service centers, warehouses, garages, cafeterias, and other service buildings. Approximately 42 percent of the buildings are 30 years of age or older. Temporary facilities total almost 8 percent of the total inventory. Approximately 39 percent of the space is in poor or fair condition. Of the total work force 62 percent is housed in office areas of which half (16,000 persons) is considered to be in substandard office space or trailers. Similarly, many utility and road/railroad systems are old, out-moded, inefficient, uneconomical, and prone to failure.

Annually, through the Institutional Planning Process, the specific MGPF projects needed in the upcoming 5 years are identified. The 1983 plan contained $461,000,000 worth of MGPF projects for the period FY 1986-FY 1990. These are summarized by program category below:

Program Category	Cost of Identified MGPF Projects FY 1986-1990 (In thousands of dollars)
Buildings........................	$ 331,000
Utilities........................	91,000
Roads, Railroads and Other Site Improvements..............	39,000
Total.........................	$ 461,000

Several factors contribute to the extensive backlog:

1. Inadequate Building Practices

   Much of the agency's original physical plant was built during times of crisis when either shortages of materials or the urgency of the programs dictated utilizing inferior materials and/or rapid construction techniques. These practices have resulted in premature aging of some of the plant and expansion of routine maintenance to keep the plant on-line. More recently, as programs expanded, temporary facilities such as trailers and prefabricated buildings have been used in lieu of permanent facilities. These have a much shorter life span, and were contemplated to be temporary until more suitable facilities could be provided.

2. Aging and Deterioration

   The aging and wear of facilities, particularly utility systems, affect the reliability of service and increase the downtime and routine maintenance costs for most systems. Real property at the laboratories averages 25 years with many of the facilities going back to the 1940's. Many of these buildings and utility systems have no remaining service life and must be replaced to continue operations at the laboratories.

3. Facility Support Lagged Operating Growth

   Improvements to support facilities did not keep up with increases in R&D programs. The result is that existing facilities have been utilized well beyond their design capacities. This is especially noticeable in utility systems, roads, and laboratory facilities. Because adequate permanent facilities have not been available, the laboratories have, of necessity, converted space designed for other purposes (e.g., warehouse space) into laboratory space, and have continued to rely on World War II barrack type buildings which are limited in application and have leased offsite space in several instances. Such solutions can seldom provide the quality laboratory space needed to meet today's research standards.

4. Lack of Institutional Support for GPF

   Prior to the MGPF program, the installations suffered from a lack of adequate institutional support largely because they accommodate many programs. All resident programs fund operating expenses to cover the work performed. However, only the assigned lead program (i.e., landlord) had been responsible in the past for providing general purpose facilities, which actually support many or all residing programs. More often than not, budget ceilings have prevented the lead program from accommodating both direct program requirements and institutional needs including general purpose facilities.

The impacts of these facilities' deficiencies are: increased operating costs; increased safety, security, health and environmental risks; greater likelihood of program interruption and delay; and low morale and productivity.

As part of the annual planning process for MGPF, several steps have been taken to assure that most of the above practices are not repeated.

1. The Institutional Planning and Site Development planning processes are designed to ensure orderly planning of the operation, maintenance, and development of the multiprogram laboratories. These processes require careful consideration be given to facility needs, both strategic and specific.

2. A systematic, agency-wide approach to determining funding levels for General Plant Projects (GPP) has been established and a significant effort to increase overall GPP funding has begun.

3. An improved maintenance management system is being implemented to prevent the deferral of maintenance when it is detrimental to the physical well being of necessary facilities.

4. Better project development and management during construction will be utilized to keep the quality of construction high and costs low.

5. Finally, the planning and programming process utilized by the MGPF program will assure that the proper attention is paid to potential critical deficiencies so that they may be corrected prior to any serious impact on mission accomplishment.

The FY 1986 request of $29,300,000 for the Multiprogram General Purpose Facilities (MGPF) subprogram will allow continued rehabilitation, replacement and improvement of MGPF at the national laboratories, reflecting responsible management of the Government's real property and the importance of maintaining it adequately. The replacement costs of these prior investments is over $6,000,000,000. This budget permits orderly reduction of the backlog of MGPF deficiencies; helps alleviate the serious drain on R&D programs' operating budgets resulting from conducting work in old, worn-out, out-moded and inefficient facilities; and provides for the continued effective accomplishment of DOE's R&D missions. The requested construction funding is summarized below by program category:

	FY 1985 BA (000)	FY 1986 BA (000)
Program Category:		
Buildings	$ 8,808	$ 7,150
Utilities	20,642	17,750
Roads	3,750	4,400
Total	$ 33,200	$ 29,300

The continued emphasis of the program is the upgrading of inadequate utility systems to acceptable levels of performance, reliability, and economy.

A total of $28,800,000 is required to complete or continue funding of ten projects started in previous years. These projects are identified below:

On-Going		TEC	FY 1986 BA (000)
Buildings			
80-ES-11	Laboratory Facility (INEL)	$19,500	$ 750
85-R-702	Replace Laboratory Roofs, (ANL)	9,800	3,100
85-R-706	Medical Facility Replacement (LLNL)	7,300	2,800
	Subtotal		6,650
Utilities			
85-R-701	Central Chilled Water Facility, (BNL)	15,000	7,100
85-R-703	Electrical Distribution System Restoration (ORNL)	2,200	1,400
85-R-707	Replace Site Fire Alarm System (RL)	4,850	3,550
85-R-709	Establish a Central Chilled Water Plant (ANL)	5,200	1,000
85-R-711	Upgrade Environmental Monitoring (ORNL)	3,500	2,500
85-R-712	Modify Central Chilled Water Plant (ORNL)	4,700	2,200
	Subtotal		$17,750
Roads and Other			
84-ER-103	Road Repair (LBL, INEL, RL, ANL)	19,500	4,400
	Subtotal		4,400
	Total On-Going		$28,800

The remainder of the request, $500,000 provides funds for the one new project identified below:

New		TEC	FY 1986 BA (000)
Buildings			
86-R-726	Fire protection improvements (BNL)...............	$ 3,000	$ 500
	Total New Projects		$ 500

The new project is consistent with the Department's Institutional and Site Plans for these laboratories and was selected as the highest priority project from an extensive backlog of projects to correct the deficiencies at the laboratories. Construction Project Data Sheets which describe and justify each project in detail follow the narrative.

	FY 1984	FY 1985	FY 1986 Request
Environmental Compliance (ORNL)......................	$ 0	$ 0[a]	$ 21,900

As stated earlier in the major activity overview for the Multiprogram Laboratories Facilities Support Program, the Department is faced with an extensive environmental cleanup effort at ORNL. The backlog of environmental projects identified as necessary to be undertaken to ensure compliance with existing State and Federal regulations is significant. These projects range from identifying, monitoring and cleaning up existing areas, tanks, ponds. and burial grounds containing hazardous wastes, to upgrading all ongoing systems and processes for handling hazardous wastes (both radioactive and nonradioactive).

It has been determined that $21,900,000 is required in FY 1986 to continue correcting the deficiencies at ORNL. These funds consist of operating expenses, capital equipment, and construction as follows:

	FY 1984	FY 1985	FY 1986 Request
Operating Expenses..........	$ 0	$ 0	$ 12,900

The requested operating expense funds of $12,900,000 are required for the following:

- Correct current practices which provide no treatment of discharges and earlier disposal practices which now impact the environment in and around ORNL.
- Upgrade the process waste drainage system where the 40 year old system has reached design life expectancy.
- Conduct comprehensive radiological and hazardous chemical inventories and characterize the sediment and ground water around seven temporary holding ponds known to contain varying amounts of hazardous materials. (There is possible groundwater contamination due to the ponds being unlined.)

---

[a] Pending approval of a reprogramming request, $5,400,000 will be devoted to this activity in FY 1985.

- Determine action needed to eliminate hazardous discharges from White Oak Creek, floodplains, and White Oak Lake. The lake has accumulated almost five million cubic feet of sediment containing radionuclides, PCB's, mercury, and other trace metals.

- Upgrade the sewage treatment plant and sanitary sewer system. Over the years, numerous non-sanitary drainage points have been introduced to the system. In certain instances, the non-sanitary drainage has involved hazardous and/or radioactive materials. Due to this, various contaminants have found their way into piping, treatment equipment, and associated soils surrounding parts of the system. To address these areas, certain piping, treatment equipment, and surrounding soils will require removal and disposal to preclude further spread of hazardous and radioactive materials from contaminated areas and sections of the overall monitoring system.

- During the operation of ORNL, process drainage has been inadvertently routed to the storm drainage system. Also, several spills of hazardous and/or radioactive materials that have resulted in the introduction of these materials to the storm sewer system are contaminated with hazardous and/or radioactive materials. Also, areas drained and soils surrounding the drainage system are contaminated with hazardous and/or radioactive materials. These problems result in a discharge of pollutants to the White Oak Creek watershed with the storm water drainage. Areas where contamination is present in the system or is entering the system will be addressed.

This request will allow initiation of activities to correct the above problems which can be summarized into the following categories: process waste system upgrades, hazardous and toxic material management, watershed discnarge improvements, spill site characterization and cleanup, and upgrades of sanitary and storm sewers.

	FY 1984	FY 1985	FY 1986 Request
Capital Equipment...........	$ 0	$ 0	$ 1,000

The requested capital equipment funds of $1,000,000 are required for general purpose equipment. This equipment will include analyses equipment, and sludge/soil handling equipment and will support cleanup activities described under operating expenses.

	FY 1984	FY 1985	FY 1986 Request
Construction................	$ 0	$ 0	$ 8,000

The FY 1986 budget request of $8,000,000 for construction is required for general plant projects and one line-item construction project.

1. General Plant Projects (86-R-800).............................. $ 5,000

   These projects provide for the many miscellaneous alterations, additions, modifications and replacements, of items required to reduce or eliminate environmentally harmful discharges from ORNL. The proposed projects in FY 1986 include replacing the PCB transformers, initiating a mercury collection system, installing a nonradiological waste volume reduction system, and procuring a modular cement batch plant for fixation of soil or sediment in cement.

2.	Non-radiological Process Waste Treatment Project (Design Only) (86-R-801)..	$ 3,000

The purpose of the project is to collect and treat the nonradiological waste effluents from ORNL facilities so that they will comply with the water quality requirements set by the State of Tennessee and the Environmental Protection Agency. The FY 1986 request is for AE work to perform Title I and Title II designs in order to pursue the construction as a FY 1987 project. No R&D is needed, but waste characterization and treatability studies are in progress under the operating budget.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: Fire protection improvements (phase II)
Brookhaven National Laboratory (BNL)
Upton, New York

2. Project No.: 86-R-726

---

3. Date A-E work initiated: 2nd Qtr. FY 1986

3a. Date physical construction starts: 3rd Qtr. FY 1986

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: None
Date: None

6. Current cost estimate: $ 3,000
Less FY 1984 PE&D: 0
Net cost estimate: $ 3,000
Date: December 1984

---

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1986	$ 3,000	$ 500	$ 500	$ 300
1987	0	2,500	2,500	1,700
1988	0	0	0	1,000

8. Brief Physical Description of Project

This project provides for the design, fabrication and installation of various fire protection improvements affecting over 210,000 sq. ft. of building space. The improvements consist of:

1. Providing automatic sprinkler protection in basement, laboratories and storage areas of facilities designated as high loss potential areas. Areas included are Building 510, 555, 815, 830, 901 and 928.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Fire protection improvements (phase II)
Brookhaven National Laboratory (BNL)
Upton, New York

2. Project No.: 86-R-726

8. Brief Physical Description of Project (continued)

2. Provide complete or partial automatic sprinkler protection (either new, or extension of existing systems) in buildings of combustible contents and/or construction which have a direct impact or exposure to DOE programs. These include Buildings 130, 179, 211, 355, 356, 480, 610 and 923.

3. Transferring the existing fire alarm panels from BNL's old telegraph system to BNL multiplexed central alarm station (completion of a multiplexed central alarm station is scheduled in FY 1985). This will eliminate basic operational deficiencies in the existing system and bring BNL into full compliance with general industrial standards and DOE guidelines.

4. Raising the level of fire protection at Building 30 (Brookhaven Center) and other miscellaneous buildings to improve the life safety aspects. These improvements include: modifications to exits to comply with the National Fire Protection Association (NFPA) 101 (the Life Safety Code), extending sprinkler protection into unprotected areas, installing fire extinguishing systems above localized areas of high hazards (i.e., grills, deep fat fryers).

All installations and modifications will be in accordance with DOE recommended standards. Specifically, sprinkler protection will conform to National Fire Protection Association Standard 13. Sprinkler systems will be hydraulically designed to minimize costs. Wetpipe system on 100 sq. ft. spacing will be used in heated areas. Dry pipe systems will be used for unheated or partially heated areas. Water supplies will be taken from the existing BNL site water distribution system.

Transferring the fire alarm system to BNL's new central station facility will include all the work necessary to comply with the National Fire Code's 72 Series and DOE Orders.

9. Purpose, Justification of Need for, and Scope of Project

The purpose of this project is to reduce the risk of loss due to fire at BNL. Only key facilities have been included. Key facilities are defined as:

a. Buildings containing operations directly involved in DOE program activities; or

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: Fire protection improvements (phase II)
Brookhaven National Laboratory (BNL)
Upton, New York

2. Project No.: 86-R-726

---

9. Purpose, Justification of Need for, and Scope of Project (continued)

b. Vital support buildings for program buildings

Each key facility was examined in relation to several interrelated risk factors: potential dollar loss due to fire, effectiveness and reliability of existing fire protection (if any), amount of combustibles present, type of potential fire (i.e., smokey, flash, average), access by fire department, salvageability, potential extension of fire, impact on experiments, and life safety of occupants. Automatic sprinkler protection has been proposed over fire detection since the above factors were especially unfavorable (i.e., difficult fire department access, over one million dollars loss potential, potential fire spread is great, program impact is severe).

The Gamewell telegraph portions of the system are in excess of 25 years old. Maintenance is high, alarm information provided is limited, expansion is limited and costly. The telegraph system does not indicate when a field unit resets nor does it indicate when a local system is in trouble. Transferring the fire alarm from the Gamewell System to the new multiplexed system will satisfy DOE requirements and provide an easy expandable, economical alarm system.

10. Details of Cost Estimate

	Item Cost	Total Cost
a. Engineering, design, and inspection at approximately 12% of construction costs, item b		$ 285
b. Construction costs		2,370
1. Sprinkler system installation into existing building (approximately 210,000 sq. ft. at $360/head)	$ 1,125	
2. 13 new water mains with trenching control valves and wet taps (approximately 1,200 feet at $90 per ft.)	219	
3. Connect sprinkler alarms into existing fire alarm system (15 risers at $8,400 each)	126	
4. Transfer fire alarm to new site protective signaling system (150 buildings at $6,000 each)	900	
Subtotal		2,655
c. Contingency at approximately 13% of above costs (Items a & b)		345
Total estimated cost		$ 3,000

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Fire protection improvements (phase II)
Brookhaven National Laboratory (BNL)
Upton, New York

2. Project No.: 86-R-726

11. Method of Performance

Design and inspection will be performed under one or more negotiated architect-engineer contracts with firms specializing in fire protection design. Construction and procurement will be accomplished by fixed-price contracts and purchase orders awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Not required.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

Not required.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES

(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

---

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 1st Qtr. FY 1986

4. Date construction ends: 3rd Qtr. FY 1988

5. Previous cost estimate: none
Date: none

6. Current cost estimate: $15,000
Less amount for PE&D: 0
Net cost estimate: $15,000
Date: September 1983

---

7. Financial Schedule:

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$15,000	$ 2,200	$ 2,200	$ 600
1986	0	7,100	7,100	4,260
1987	0	5,700	5,700	6,690
1988	0	0	0	3,450

---

8. Brief Physical Description of Project

This project proposes the construction of a central chilled water and compressed air facility. It will provide 5,100 tons of refrigeration and 1,500 standard cubic feet per minute (SCFM) of compressed air service for distribution to the following six major research complexes on site: Biology - Building 463; Medical Research Center - Building 490; Physics - Building 510; Applied Mathematics - Building 515; Laboratory Wings - Building 703; Hot Laboratory - Building 801.

The project consists of the installation of approximately 16,000 feet of underground chilled water piping and 8,000 feet of compressed air piping; the erection of one 5,100 ton capacity multicell cooling tower of completely fireproof construction and two buildings (a central chilled water and compressed air structure, and a condenser water pump house) having a total gross area of approximately 6,140 square feet and a gross volume of 115,100 cubic feet. Necessary switchyear at 13.8 KV, 2.4 KV and 480 volts, and a 500 KVA transformer substation are also included. Certain utility systems that interfere with construction will be extended, modified, or relocated; these include steam, water, electric power, telephone, and storm and sanitary drains. The present macadam service road (Temple Place) located adjacent to the central steam plant will be extended (20' x 50') in order to provide access to the proposed facility.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

8. Brief Physical Description of Project (continued)

The building identified as central chilled water and compressed air structure will be approximately 56' x 90' x 20' high. This building will abut and connect with the south wall elevation of the existing central steam facility.

The building will be approximately 5,040 square feet and will consist of slab-on-grade, steel framing, insulated sandwich wall siding with a built-up insulated roof deck.

The equipment level at grade will contain the following major refrigerations apparatus and associated components: Three 1,700 ton chillers, one 1,500 SCFM air compressor, three chilled water pumps, an automatic central control and monitoring system, electrical switchgear, motor control stations and associated piping and electrical lines.

The condenser water pump house of approximately 1,100 square feet will house two vertical condenser water pumps, and will be constructed with a slab-on-grade, concrete block walls, and built-up roof deck.

9. Purpose, Justification of Need for, and Scope of Project

This project is the most cost effective method for replacing major refrigeration and compressed air equipment that have become obsolete and beyond economical repair. The multiple independent systems that exist at Brookhaven National Laboratory historically have ever increasing operating and maintenance costs as the equipment ages. A new central chilled water facility would have lower maintenance and operating cost, and be able to maximize load diversity presently not possible with the independent building systems.

This project provides a firm base for substantial future reductions in capital construction, maintenance costs and energy consumption. In the future, work and spent individual air conditioning and compressed air systems in other scientific buildings will be replaced with chilled water and compressed air from the proposed central facility.

Background Profile of Existing Systems and Facilities

The existing decentralized systems of air conditioning, refrigeration, and compressed air are the result of each system being conceived as a self-contained entity as opposed to other basic utility services such as electrical power, potable water, waste water, steam, gas, etc., which are extended to a new facility from a central source. Chilled water, however, presently requires refrigeration units (centrifugal, steam absorption, etc.), cooling towers, pumps, electrical equipment, etc. to provide complete and independent systems for supplying environmental air conditioning to each building. This approach has resulted in a multiplicity of equipment and systems.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

9. Purpose, Justification of Need for, and Scope of Project (continued)

The major buildings are presently served by 36 units consisting of steam absorption, centrifugal and helical screw, refrigeration water chillers totaling 11,147 tons.

There are approximately 6,500 tons of additional refrigeration installed throughout various complexes. These range from small one-ton window air conditioning units to 150-ton reciprocating refrigeration assemblies.

Proposed Central Chilled Water Facility

It is proposed to construct a central chilled water and compressed air facility as a utility similar to other central facilities. The new chilled water plant will supply the refrigeration requirements for the six buildings and eliminate the use of well water used for once-through cooling at the Medical Research Center. The cooling systems being replaced were installed in the 1950s and 1960s and are obsolete, and beyond their normal life expectancy, and incur increasing operational and maintenance costs each year. In addition, this proposed facility would supply a source of clean, oil-free, low dewpoint compressed air for experimental and utility services within these facilities.

The proposed central chilled water and compressed air facility offers many tangible benefits over the multiplicity of the decentralized systems. Some of the major benefits are:

A. Permit new refrigeration systems to be installed at a lower initial cost ($360/ton) as compared with separate, independent systems ($790/ton).

B. Reduce operating and maintenance costs due to the elimination of independent chilled water and compressed air systems by centralization of major equipment.

C. Reduce capital installation costs due to utilization of load diversity among the various complexes.

D. Provide two additional proven wells for integration with the laboratory's potable and firefighting water supply system. The two existing wells in the Medical Research Center used for once-through cooling can be diverted to reinforce the domestic water system capacity.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

9. Purpose, Justification of Need for, and Scope of Project (Continued)

E. Provide for restructuring of the laboratory's present steam supply by removing from service the existing steam absorption machines (used for cooling). Approximately 148 million pounds of steam per year will be redeployed for better utilization (e.g., 20,000 lbs. of steam per hour for winter heating in lieu of winter air conditioning).

F. Permit the recycling of treated effluent from the central sewage facility for use as make-up at the central steam plant and the proposed central chilled water and compressed air plant. This would reduce the load on the potable water system by approximately 600 gpm.

G. Utilize the return tower condenser water to preheat boiler water make-up (approximately 25,000 GPD) at the Central Steam Facility conserving approximately 90 million pounds of steam a year (equal to saving 700,000 gallons of No. 6 fuel oil).

H. Reduce the energy costs at the six buildings by approximately 56% in today's dollars due to improved utilization and diversity source.

10. Details of Cost Estimate

		Item Cost	Total Cost
a. Architect-engineer, design and inspection at approximately 12% of construction costs, Item c			$ 1,400
b. Land and land rights			0
c. Construction costs			11,600
(1) Improvements to Land		$ 98	
Site preparation (L.S.)	$ 60		
Road and area surfacing, 1000 S.Y. @ $28	28		
Area lighting (L.S.)	10		
(2) Buildings (6,140 S.F. @ approximately $136)		833	

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

10. Details of Cost Estimate (continued)

		Item Cost	Total Cost
(3) Equipment (within buildings)		6,050	
1700-ton machine (3) @ $516,000	$ 1,548		
Primary chilled water pumps (3) @ $39,000	117		
Secondary chilled water pumps (6) $14,000	84		
Air compressor (1)	187		
Chilled water, condenser, water, compressed air piping and miscellaneous accessories and equipment including six building tie-ins	2,789		
Condenser water pumps (2) @ $52,000	104		
Chemical water treatment system	91		
Automatic central control and monitoring system	905		
Electrical switchgear and distribution	225		
(4) Cooling Tower		536	
(5) Utilities		4,083	
Relocation of piping, electric lines, sewer and storm piping telephone, switchgear and distribution	932		
Chilled and condenser water supply and return piping	2,208		
Compressed air piping, valves (approximately 30 @ $6500), excavation, backfill, etc. for all underground utilities (10,000 ft. @ $46 per ft.)	943		
Subtotal			$13,000
d. Contingency @ approximately 15% of above costs			2,000
Total estimated cost			$15,000

11. Method of Performance

Design and inspection will be performed under a negotiated architect-engineer contract. Construction and procurement will be accomplished by fixed-price contracts awarded on the basis of competitive bidding.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1985	FY 1986	FY 1987	FY 1988	Total
a. Total project costs						
1. Total facility costs						
(a) Construction line item ..	$ 0	$ 600	$ 4,260	$ 6,690	$ 3,450	$15,000
(b) PE&D	0	0	0	0	0	0
(d) Inventories	0	0	0	0	0	0
Total facility costs ..	0	$ 600	$ 4,260	$ 6,690	$ 3,450	$15,000
Total project costs	$ 0	$ 600	$ 4,260	$ 6,690	$ 3,450	$15,000

b. Other related annual costs (estimated life of project: 20 years)

1. Facility operating cost	$1,549
2. Programmatic operating expenses directly related to the facility	0
3. Capital equipment not related to construction but related to the programmatic effort of this facility	0
4. GPP or other construction related to the programmatic effort in the facility	0
5. Other costs	0
Total related annual costs	$ 1,549

The $1,549,000 annual operating cost is estimated as follows:

Maintenance and Operation	$ 317,000
Energy (Utilities)	1,232,000
Total operating costs	$1,549,000

However, if this facility is not funded, the existing systems in the six (6) buildings previously mentioned will have an annual operating cost as follows:

Maintenance and Operation	$ 578,000
Energy (Utilities)	2,341,000
Total operating costs	$2,919,000

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water facility
Brookhaven National Laboratory
Upton, New York

2. Project No.: 85-R-701

12. Funding Schedule of Project Funding and Other Related Funding Requirements (continued)

The annual savings of non-energy is $261,000 and energy is $1,109,000 for this proposed facility, when constructed.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project funding
  1. Total facility
    (a) Construction line item - Not required
    (b) CP&D - Not required
    (c) Expense funded equipment - Not required
    (d) Inventories - Not required

  2. Other project funding
    (a) R&D necessary to complete - Not required
    (b) Other project related funding - Not required

  3. Capital equipment not related to construction but related to the activity effort in the facility.
     Not required

  4. GPP or other construction related to programmatic effort
     Not required

  5. Other costs
     Not required

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Replace laboratory roofs
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-702

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 4th Qtr. FY 1985

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: none
Date: none

6. Current cost estimate: $ 9,800
Less amount for PE&D: 0
Net cost estimate: $ 9,800
Date: December 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$ 9,800	$ 3,308	$ 3,308	$ 2,030
1986	0	3,100	3,100	4,000
1987	0	3,392	3,392	3,770

8. Brief Physical Description of Project

The proposed project will replace built-up membrane roofs on principal general purpose laboratory buildings, giving priority to existing conditions. Approximately 880,000 sq. ft. of roof will be replaced. The work will consist of stripping existing membrane and insulaton where conditions require, patching decks as required, improving drainage by compensating for low spots, installing new current technology membranes designed to best fit field conditions, adding insulation to bring heat transfer resistance up to current DOE standards, and, finally, providing protection to the membranes from temperature extremes and attack from photochemical activity. Flashings, curbs, gravel stops, and fascia will be renewed as their conditions dictate. Satisfactory function of roofing components will be warranted for 10 years, directly by the material manufacturers.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Replace laboratory roofs
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-702

9. Purpose, Justification of Need for, and Scope of Project

The purposes of this project are to restore the weather tightness of roofs on laboratory buildings, and to bring the resistance to heat transfer up to current Federal energy use standards. This project provides a multi-year plan, described in the ANL Institutional Plan, FY 1983-FY 1985, whose goal is the replacement of all roofs older than 25 years on permanent general purpose buildings. At this age they have exceeded normal life expectancy for conventional built-up membrane construction. Resources expended on reconditioning efforts exceed good business judgment, yet the research programs housed under the roofs have been impacted.

Total replacement is required. Programs housed in these buildings include Basic Energy Research, Fossil Energy Research, Conservation, Renewable Energy, Environmental Protection, Safety, and Emergency Preparedness. Twenty one buildings are scheduled with approximately 880,000 square feet of roof needing immediate attention.

10. Details of Cost Estimate

ANL has replaced over 70,000 square feet of roofs since 1982 under five separate competitively bid contracts. In addition to the roof area, the amount of roof and insulation to be removed, the relative number of roof penetrations and other complications to be provided all produced a range of unit prices from $6.03 to $8.68 per square foot when normalized to mid-1982. The mean unit cost derived from these bids was $7.30 in mid-1982.

The various elements contributing to the total unit cost of roof replacement are identified in the following table:

Job Cost Breakdown

Cost Element	$ Per Sq Ft Mid-1982
Tear-off of old roof and insulation (90% of roof area)	$1.34
Preparation of substrate	0.38
Improve water drainage (average)	1.04
Single-ply PVC membrane	1.48
Irma Board - 2" thick insulation	2.04
Pro-rated edge and penetration details (average)	1.02
Warranties (included in above costs)	--
Estimated total	$7.30

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Replace laboratory roofs
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-702

10. Details of Cost Estimate (continued)

The following estimated total cost of the project is for the construction of approximately 200,000 square feet for three years, 80,000 square feet in the last year of the project. The above unit cost of $7.30 in mid-1982 has been escalated for each annual increment of construction, using the escalation rates projected below.*

	Total Cost
a. Engineering, design and inspection at approximately 11% of construction, Item b.	$ 900
b. Construction costs, 880,000 sq. ft. @ $10.80/sq. ft.	8,000
c. Contingency @ approximately 10% of above costs	900
Total estimated cost...	$ 9,800

*Based upon a completed conceptual design and current cost data.

11. Method of Performance

Engineering, design and inspection will be performed by laboratory engineering personnel. Construction will be accomplished by fixed-price contracts awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1985	FY 1986	FY 1987	Total
a. Total project costs					
1. Total facility costs					
(a) Construction line item ..	0	$ 2,030	$ 4,000	$ 3,770	$ 9,800
(b) PE&D	0	0	0	0	0
(c) Expense funded equipment.	0	0	0	0	0
(d) Inventories	0	0	0	0	0
Total facility costs .	0	$ 2,030	$ 4,000	$ 3,770	$ 9,800

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Replace laboratory roofs
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-702

12. Funding Schedule of Project Funding and Other Related Funding Requirements (continued)

	Prior Years	FY 1985	FY 1986	FY 1987	Total
2. Other project costs					
(a) R&D necessary to complete construction	0	0	0	0	0
(b) Other project related costs	8	0	0	0	8
Total other project costs	$ 8	$ 0	$ 0	$ 0	$ 8
Total project costs (Items 1 and 2)	$ 8	$ 2,030	$ 4,000	$ 3,770	$ 9,808

b. Other related annual costs (estimated life of project: 20 years)

1. Facility operating costs	0
2. Programmatic operating expenses directly related to the facility	0
3. Capital equipment not related to construction but related to the programmatic effort in the facility	0
4. GPP or other construction related to programmatic effort in the facility	0
5. Other costs	0
Total other related annual costs	0

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project funding
  1. Total facility
    (a) Construction line item - No narrative required
    (b) PE&D - None
    (c) Expense funded equipment - None
    (d) Inventories - None

  2. Other project funding
    (a) No R&D effort is required
    (b) $8,000 spent for conceptual design

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Replace laboratory roofs
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-702

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

b. Total related funding requirements - The roofing components to be replaced or rehabilitated will have useful lifetimes of approximately 20 years.

1. Facility operating costs - Implementation of this project will rehabilitate or replace physical components of buildings. This will result in a reduction of maintenance costs while restoring the respective system components to an acceptable level of operational efficiency, thus the facility operating cost is reported as zero.

2. Programmatic operating expenses directly related to the facility - Although this project will rehabilitate general purpose facilities employed to perform a wide variety of activities, there is no programmatic operating expense directly related to, or required for supply of this project, thus the programmatic operating expenses is reported at zero.

3. Capital equipment not related to construction but related to the programmatic effort in the facility - None

4. Maintenance, repair, GPP or other construction related to programmatic effort - None

5. Other costs - None

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Primary electrical distribution system restoration
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-703

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 4th Qtr. FY 1985

4. Date construction ends: 4th Qtr. FY 1987

5. Previous cost estimate:
Date: none

6. Current cost estimate: $ 2,200
Less amount for PE&D: 0
Net cost estimate: $ 2,200

Date: September 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$ 2,200	$ 800	$ 800	$ 360
1986	0	1,400	1,400	1,300
1987	0	0	0	540

8. Brief Physical Description of Project

This project will involve a series of restoration activities which will increase the reliability of the existing electrical distribution system to an appropriate level. These activities will include repair or replacement of deteriorated components, replacement of deficient items, and the elimination of potential safety and environmental hazards. Deteriorated equipment to be replaced includes wooden poles, transformers, and cables. Correction of deficiencies include replacing fused disconnect switches with electrically-operated circuit breakers, improving lightning protection of overhead lines, and replacement of single-pole switches with three-pole switches. Correction of potential safety hazards includes additional isolation switches for buildings and facilities and improved relaying. Correction of potential environmental hazards includes replacing deteriorated liquid-filled (oil and polychlorinated biphenol [PCB]) transformers.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Primary electrical distribution system restoration
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-703

9. Purpose, Justification of Need for, and Scope of Project

This project will renew and upgrade the existing primary electrical distribution system to an appropriate level of reliability and enable it to effectively support various research activities at the Laboratory. Much of this system at Oak Ridge National Laboratory (ORNL) was built in 1943. Many of the components are beyond their expected life and are showing clear evidence of deterioration to the point where an escalating number of failures are projected. Examples of this deterioration are: (1) several oil filled transformers which have become severely corroded internally due to moisture and acid content will be replaced; (2) fused disconnect switches will be replaced with the electrically operated circuit breakers; (3) unshielded cable which is in violation to the National Electric Code will be replaced with approved shielded cable; (4) lightning protection will be improved on those circuits supplying the High Flux Isotope Reactor, Transuranium Processing Plant, Health Physics Research Reactor and to the Tower Shielding Facility thereby increasing the reliability of these circuits.

In addition, single pole switches will be replaced with three pole switches. This change will allow operating personnel to be better utilized during emergency conditions and reduce switching time which results from waiting for called in maintenance personnel.

The cost estimate is based on a conceptual design completed during FY 1982 and will be issued during FY 1983 at an estimated cost of $20,000.

10. Details of Cost Estimate*

	Item Cost	Total Cost
a. Engineering, design, and inspection at approximately 13% of construction costs, item b		$ 220
b. Construction costs		1,720
(1) Outside utilities	$, 1,720	
Subtotal		$ 1,940
c. Contingency at approximately 13% of above costs		260
Total estimated cost		$ 2,200

*Based on a Conceptual Design Report completed in FY 1982 at a cost of approximately $20,000.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Primary electrical distribution system restoration
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-703

11. Method of Performance

Design and inspection will be performed under a negotiated architect-engineer contract. Construction and procurement will be accomplished by fixed-price contracts awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Not Required. TEC is less than $5,000,000.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

Not Required. TEC is less than $5,000,000.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Medical facility
Lawrence Livermore National Laboratory
Livermore, California

2. Project No.: 85-R-706

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 1st Qtr. FY 1986

4. Date construction ends: 1st Qtr. FY 1988

5. Previous cost estimate: None
Date: none

6. Current cost estimate: $ 7,300
Less amount for CP&D: 0
Net cost estimate: $ 7,300
Date: September 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$ 7,300	$ 500	$ 500	$ 350
1986	0	2,800	2,800	2,300
1987	0	4,000	4,000	4,650

8. Brief Physical Description of Project

This project will provide a 25,600 gross square foot building for a new and expanded facility for Health Services and will house all of the 32 medical staff and support personnel. The functions accommodated in this space will be a waiting area, receptionist, interview rooms, administrative offices, records area, health maintenance offices, physical examination rooms, observation room, emergency treatment (major and minor), diagnostic laboratories, specimen rooms, X-ray room, dark room/process lab, autoclave and clean hold area, ambulance entry, personnel decontamination facility, eye safety examination rooms, toilets, storage and equipment rooms.

The building will be designed to relate to the existing nearby major facilities and will be constructed of fire-resistive materials. Fire sprinkler system as well as other safety devices, will be installed. Normal medical laboratory building utilities, heating, ventilation, power, lighting, and communication systems will be provided. The building will be cooled by mechanical refrigeration. In addition, the decontamination area will require special ventilation, sewage retention tanks, and floor treatment. Energy conserving design will be utilized throughout the facility.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Medical facility
Lawrence Livermore National Laboratory
Livermore, California

2. Project No.: 85-R-706

8. Brief Physical Description of Project (continued)

Normal site utilities will be extended from mains and connections to storm and sanitary sewers will be made. Electrical power will be extended from high voltage feeders to a new substation serving this building. Area lighting will be installed for safety and security. Site development will comply with the Master Site Plan and will include grading, paving, off-street parking, curbs, gutters, sidewalks, fencing, security screens, and minimal landscaping.

9. Purpose, Justification of Need for, and Scope of Project

Adequate health service support to the over 7600 employees of Lawrence Livermore National Laboratory (LLNL) primarily consists of two major elements. First, preventative approaches to both the physical and mental health of the workforce. This is accomplished through performance of over 3500 physical examinations a year, attention to the potential hazards of one of the country's foremost applied physics and engineering facilities and support to those who may be unduly stressed by working in such an environment. Second, is the availability of adequate emergency response to a very broad spectrum of hazards ranging from intense radioactivity, through almost every possible chemical, mechanical and electrical risk, to the "normal" falls, cuts, etc., that go with a dynamic population that includes over a thousand contractor employees in addition to the LLNL staff. Although blessed with one of the best safety records of the national laboratories, the health services facility must be prepared for major incidents.

The current health facility is housed in a 40 year old World War II barracks building that is shared with the South Badge Office. It was barely adequate for a medical staff of less than 20 and a population of less than 5,000. Today the building limits physical examinations to approximately two thirds of the DOE guidelines for a laboratory of LLNL's size. Several other health services required by DOE order, DOT regulation, California code, American National Standards Institute (ANSI) standards, and LLNL policy are currently not being provided due to the physical restraints of the current building. For example, in the event of persons being contaminated with radioactive, toxic, or carcinogenic materials, they cannot be adequately treated without significant risk to the current facility and attending personnel. A special unit needs to be constructed to deal with this particular type of emergency situation. The present facility is generally not capable of handling a large variety of emergency situations nor a large number of casualties.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Medical facility
Lawrence Livermore National Laboratory
Livermore, California

2. Project No.: 85-R-706

10. Details of Cost Estimate*

	Item Cost	Total Cost
a. Engineering, design, and inspection at approximately 13% of construction costs		$ 700
1) Title I & II	$ 400	
2) Title III	300	
b. Construction costs		5,550
1) Improvements to land including grading, paving, walks and landscaping	550	
2) Buildings Medical, 25,600 sq. ft. at $162 per sq. ft.....	4,150	
3) Utilities, including mechanical, power, communications, storm and sanitary sewer.	850	
c. Standard equipment		140
d. Relocation cost		100
Subtotal		$ 6,490
f. Contingency at approximately 12% of other costs (except item a. and c. above)		810
Total estimated cost.....		$ 7,300

*Based on complete conceptual design.

11. Method of Performance

This project will be designed and constructed under a procedure commonly referred to as turnkey contracting. The project will be competitively bid with each bidder submitting a design and cost proposal. Minor work will be performed by LLNL forces.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Medical facility
Lawrence Livermore National Laboratory
Livermore, California

2. Project No.: 85-R-706

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1985	FY 1986	FY 1987	Total
a. Total project costs					
1. Total facility costs					
a. Construction line item	$ 0	$ 350	$ 2,300	$ 4,650	$ 7,300
b. CP&D	0	0	0	0	0
c. Expense funded equipment ..	0	0	0	0	0
d. Inventories	0	0	0	0	0
Total direct costs	$ 0	$ 350	$ 2,300	$ 4,650	$ 7,300
2. Other project costs					
a. R&D necessary to complete construction	120	0	0	0	120
b. Other project related costs	0	0	0	0	0
Total other project costs	120	0	0	0	120
Total project costs	$ 120	$ 350	$ 2,300	$ 4,650	$ 7,420

b. Other related annual costs (estimated life of facility: 40 years)

1. Facility operating costs	$ 230
2. Programmatic operating expenses directly related to the facility	3,280
3. Capital equipment not related to construction but related to the programmatic effort in the facility	300
4. GPP or other construction related to programmatic effort in the facility	100
5. Other costs	0
Total other related annual funding costs	$ 3,910

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Medical facility
Lawrence Livermore National Laboratory
Livermore, California

2. Project No.: 85-R-706

---

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

- a. Total project funding
  - 1. Total facility costs
    - a. Construction line item - No narrative required.
    - b. Expense funded equipment - No narrative required.
    - c. Inventories - No narrative required.
  - 2. Other project funding
    - a. R&D necessary to complete construction
      Total funding in this classification represents the conceptual design cost and other studies determined to be necessary.
    - b. Other related project cost - No narrative required.

- b. Total related-funding requirements

  1. Facility operating costs - Operating costs of the facility are estimated to be $226,000 per year including $92,900 escalation (based on FY 1982 average maintenance and utility cost of $5.20 per sq. ft. escalated to $8.83 in FY 1987. Maintenance cost escalated at 7% per annum, and utility cost escalated at 15% per annum).

  2. Programmatic operating expenses directly related to the facility - This estimate is for 32 total programmatic and support personnel at $102,540 average per person in FY 1987. Ninety percent of these people are presently housed in existing scattered buildings and trailers and will be moved to this new facility. The operating funds for these people are a normal part of the past and current programs. The remaining 10 percent represent growth projected to FY 1987. Funds for this growth have been included in program projections.

  3. Capital equipment not related to construction but related to the programmatic effort in the facility - This is an average annual estimate which includes both the small items needed for continuous operation of the facility and the occasional large item over $100,000 which cannot be described at this time, but can be predicted as needed to maintain technical excellence in efforts conducted in the facility.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Medical facility
Lawrence Livermore National Laboratory
Livermore, California

2. Project No.: 85-R-706

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements (continued)

4. Maintenance, repair, GPP or other construction related to programmatic effort - None

5. Other costs - No narrative required.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Hanford site fire alarm system upgrade
Richland, Washington

2. Project No.: 85-R-707

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 2nd Qtr. FY 1986

4. Date construction ends: 2nd Qtr. FY 1987

5. Previous cost estimate: none
Date: none

6. Current cost estimate: $ 4,850
Less amount for PE&D: 0
Net cost estimate: $ 4,850
Date: September 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$ 4,850	$ 1,300	$ 1,300	$ 840
1986	0	3,550	3,550	2,145
1987	0	0	0	1,865

8. Brief Physical Description of Project

This project provides for the design, procurement and construction of an upgraded fire alarm system which will be commensurate with required levels of protection for the Hanford Site. The project will replace all existing master alarm boxes and street boxes with radio boxes, replace alarm receiving equipment and consoles at the fire stations, and provide a computer aided dispatch system.

This project will replace approximately 240 master alarm boxes and 50 street boxes, which are distributed throughout the site. This will require additional equipment to interface the new master boxes with the existing detector circuits in the facilities. The existing alarm receiving equipment at the fire stations will be replaced with new equipment compatible with the new alarm boxes. Significant features of the new alarm receiving equipment includes printout of facility location and alarming zone within the facility. This equipment will be supplemented with a new computer aided dispatching system. This will increase the efficiency of responding emergency personnel by providing information not available with the existing system. This includes information such as type of occupancy, recommended extinguishing agents, and adjacent conditions.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Hanford site fire alarm system upgrade
Richland, Washington

2. Project No.: 85-R-707

9. Purpose, Justification of Need for, and Scope of Project

The purpose of this project is to update the existing fire alarm system with a more reliable and efficient system. There has been no significant overhaul of the Hanford fire alarm system since the site was originally established in the early 1940's. Some system components are approaching 50 years in age. Repair of components is difficult at best due to the lack of spare parts. Overhead conductors are generally in excess of 20 years old with significant amounts in excess of 30 years old. Due to the normal aging process the insulation of these conductors is brittle and breaks easily leaving conductors exposed and permitting faults in the system. In some locations, alarms are transmitted to the fire stations on underground conductors. Major portions of these lines are uncharted and are subject to dig-ups during construction and maintenance activities.

Due to deterioration and age of the system components, numerous false and nuisance alarms as well as ground faults occur. Records of alarm signals for calendar years 1979, 1980 and 1981 indicate alarms due to electrical problems, malfunctions, atmospheric phenomenon, and equipment failures ranged between 28 and 37 percent of the total number of alarms received. It is estimated that the proposed system could eliminate 50 percent of these alarms.

As the facilities at the site have been increased in size as well as number, additions to the fire alarm reporting system have been made to cover them. Unfortunately, by necessity, requirements of the National Fire Codes have been violated. These violations concern connection of detectors to master alarm boxes in an unacceptable manner, inadequate annunciation, and inappropriate alarm receiving at the fire stations.

The need for the fire alarm system upgrade is based on an audit report done in June 1982 by consultants specializing in fire protection and safety engineering. The audit report identifies 30 categories of deficiencies within the existing fire alarm system. An Engineering Study addressed alternative solutions for correcting existing deficiencies. Through the site survey, overall system analysis, and the consultant's fire alarm system expertise, it was concluded that to achieve compliance with NFPA, ensure system reliability, future flexibility and ease of operation, a Radio fire alarm system alone fulfilled these requirements.

Delay of this project will increase the risk of serious fire accidents due to continued aging of the system and its components. Also, maintenance costs of the existing system will continue to increase.

CONSTRUCTION PROJECT DATA SHEET

1. Title and location of project: Hanford site fire alarm system upgrade Richland, Washington	2. Project No.: 85-R-707

10. Details of Cost Estimate

		Item Cost	Total Cost
a.	Engineering design and inspection at approximately 13% of construction costs		$ 500
b.	Construction costs		3,720
	(1) Construction (includes equipment and labor)	$ 1,910	
c.	Standard equipment includes 6 consoles ($54,000/ea.) computer aided dispatch system ($204,000) and approximately 278 radio alarm boxes ($4,600/ea.)	1,810	
	Subtotal		$ 4,220
d.	Contingency at approximately 15% of above cost		630
	Total estimated cost.............		$ 4,850

11. Method of Performance

Design, inspection, and construction will be accomplished by fixed-price contracts awarded on the basis of competitive bidding. It will be a design, procure and install contract as presently planned.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Not required. TEC is less than $5,000,000.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

Not required. TEC is less than $5,000,000.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Central chilled water plant
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-709

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 2nd Qtr. FY 1987

4. Date Construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: none
Date: none

6. Current cost estimate: $ 5,200
Less amount for PE&D: 0
Net cost estimate: $ 5,200
Date: September 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1986	5,200	1,000	1,000	750
1987	0	4,200	4,200	3,000
1988	0	0	0	1,450

8. Brief Physical Description of Project

This project establishes a central water chilling plant to serve all the principal buildings in the central research group. Two new electric centrifugal chillers totaling 3200 tons are planned for a now-unoccupied area of the former Zero Gradient Synchrotron (ZGS) facilities. Use is made of existing cooling towers, pumps, piping, and electrical power. Approximately 3 miles of chilled water supply and return piping are routed to the user buildings. Local terminal connections are included. The connecting pipeline is specified as uninsulated, corrosion-resistant plastic pipe, buried below frost line. New chilled water circulation pumps are included for the control facility, with necessary pump modifications of the terminal delivery points.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water plant
   Argonne National Laboratory
   Argonne, Illinois

2. Project No.: 85-R-709

9. Purpose, Justification of Need for, and Scope of Project

The proposed project offers an integrated, cost-saving alternate to piecemeal replacing of worn out water chillers. The water chillers installed during construction of the Laboratory are beyond their normal life expectancy; to maintain active research operations, the ANL Institutional Plan, 1983-1988, identifies a nearly $6,000,000 program of chiller replacement. By establishing a central water chilling plant, greater reliability and more economical operations are possible. A 1977 ANL engineering study aimed at integrated water chilling facilities identified the savings and also pointed to savings possible by retiring steam-driven chillers in favor of electrical. However, when combined with the unavoidable necessity of replacing worn out chillers, the central plant concept is definitely attractive, offering both immediate benefits and greatly enhanced potentials. The annual estimated savings in energy, repair, and maintenance, in 1983 dollars, is approximately $500,000 for providing a central chilled water plant to replace eight existing steam driven chillers in the above mentioned four buildings.

In addition to the benefits of central chilled water supply, this project makes use of existing facilities: i.e., the vacant area in Building 370 and the under-utilized electric substations and pumped cooling tower water lines from the cooling tower near Building 370. If these under-utilized facilities were not available, a new building for the central chillers complete with new cooling towers, pumps, and electrical substation would have to be constructed at an additional cost to the project of $763,000. The capacity built into the existing facilities will accommodate the central chilling concept, yet allow a generous margin to attract future research programs. Superimposing the water chilling function offers assurance that the existing facilities will remain profitably available in good condition.

10. Details of Cost Estimate

	Item Cost	Total Cost
a. Engineering, design and inspection at 18% of construction, Item b		$ 600
b. Construction costs		3,270
(1) Valve pits	$ 135	
(2) Trenching and backfill	460	
(3) Buried chilled water piping	1,280	
(4) Piping and equipment within buildings	1,170	
(5) Controls and metering	60	
(6) Electrical power for chillers and pumps	165	

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water plant
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-709

10. Details of Cost Estimate (continued)

	Total Cost
c. Procurement costs (chillers, primary pumps & strainer)	600
d. Contingency - 16.3% of engineering, construction & procurement	730
Total estimated cost	$ 5,200

11. Method of Performance

Engineering, design and inspection will be performed by laboratory engineering personnel, aided by outside A/E firms. Construction will be accomplished by fixed-price contract awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1986	FY 1987	FY 1988	Total
a. Total project costs					
1. Total facility costs					
(a) Construction line item	$ 0	$ 750	$ 3,000	$ 1,450	$ 5,200
(b) PE&D	0	0	0	0	0
(c) Expense funded equipment	0	0	0	0	0
(d) Inventories	0	0	0	0	0
Total facility costs	$ 0	$ 750	$ 3,000	$ 1,450	$ 5,200
2. Other project costs					
(a) R&D necessary to complete construction	0	0	0	0	0
(b) Other project related costs	20	0	0	0	20
Total other project costs	$ 0	$ 0	$ 0	$ 0	$ 0
(Items 1 and 2)	$ 20	$ 750	$ 3,000	$ 1,450	$ 5,220

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water plant
Argonne National Laboratory
Argonne, Illinois

2. Project No.: 85-R-709

12. Funding Schedule of Project Funding and Other Related Funding Requirements (continued)

   b. Total related funding requirements (estimated life of project: 20 years) - N/A

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

   a. Total project funding
      1. Total facility costs (N/A)

      2. Other project funding
         (a) No R&D effort is required
         (b) $20,000 spent for conceptual design

   b. Total related funding requirements - The central water chilling facility to be established will have a useful lifetime upwards of 20 years.

      1. Facility operating costs - Implementation of this project will replace existing physical functions within individual buildings with a central plant. This will result in a reduction of maintenance and operating costs while restoring an acceptable level of operational efficiency to existing facilities, thus the facility operating cost is reported as zero.

      2. Activity operating expenses directly related to the facility - Although this project will restore and replace general purpose facilities employed to perform a wide variety of activities, there is no activity operating expense directly related to, or required for support of this project, thus the activity operating expense is reported as zero.

      3. Capital equipment not related to construction but related to the activity effort in the facility - None.

      4. GPP or other construction related to activity effort - None

      5. Other costs - None

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Upgrade environmental monitoring systems
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-711

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 1st Qtr. FY 1986

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: none
Date: none

6. Current cost estimate: $ 3,500
Less amount for PE&D: 0
Net cost estimate: $ 3,500
Date: September 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$ 3,500	$ 1,000	$ 1,000	$ 700
1986	0	2,500	2,500	750
1987	0	0	0	1,300
1988	0	0	0	750

8. Brief Physical Description of Project

The purpose of the proposed project is to modernize existing liquid and gaseous environmental monitoring stations at Oak Ridge National Laboratory (ORNL); to add additional stations to provide more detailed coverage of the surrounding area; and to provide new data handling capabilities. The monitoring information will be transmitted to a central location for processing and analysis. As presently envisioned, the work will include the following:

A. Gaseous Effluents

(1) Reinstrument selected existing air monitoring stations and add new stations. Stations will be instrumented for radioiodine, wet and dry radioactive fallout, and radioparticulate collection. Stations may also be equipped with thermoluminescent dosimeters, and will perform air concentration determinations for alpha- and beta-gamma particulates and noble gas activity. Continuous radioisotopic analysis, tritium gas monitoring and SO_2 monitoring may be performed at selected stations.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Upgrade environmental monitoring systems
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-711

8. Brief Physical Description of Projects (Continued)

(2) Add real-time, representative stack-gas monitoring-complex system(s) at one or more existing off-gas stacks to provide isotopic analyses of radionuclides. Near real-time data will be telemetered as required.

B. Liquid Effluents

(1) Reinstrument selected existing and add new proportional sampling stations. Proportional sampling stations will include one near the Melton Hill Dam and one downstream of the ORNL complex.

(2) Add continuous liquid effluent monitoring systems. These systems may be located at White Oak Creek.

C. Data Collection and Analysis

Install a computerized system to receive parametric and diagnostic information from the liquid and gaseous monitoring stations. Central readout panels will be provided.

9. Purpose, Justification of Need for, and Scope of Project

A. General

It is the Department of Energy (DOE) policy, that all off-site effluents be reduced to "as low as reasonable achievable" levels. The ORNL monitoring systems that were installed 25 years ago are insufficient in precision and are unable to measure the specific effluents that are required by the DOE Orders. The 25 year old monitoring instrumentation presently in use has inherent background levels which are too high to permit required measurements at current levels. Further improvements in keeping with the "as low as reasonably achievable" requirement will require more sensitive instrumentation. Such instrumentation is commercially available at this time. The proposed computerized system will be used to analyze and compare the data with past norms to provide early indications of long-term trends that may be developing.

The present instrumentation is also inadequate to predict with either reasonable accuracy or adequate time the consequences of an unplanned release from the Laboratory. Only a few gross parameters are measured at ORNL's discharge points and in the environment. Very little of this information is telemetered for processing and analysis, so that it could be used in responding to such a release.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Upgrade environmental monitoring systems
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-711

9. Purpose, Justification of Need for, and Scope of Project

B. Air Monitoring System Replacement

The root cause of the deficiencies in the air monitoring systems is the age of the stations themselves. They use vacuum-tube electronics which are 25 years old and reliable parts are no longer available. Some replacement parts require frequent replacement (e.g., as often as once a month for certain vacuum tubes). Other deficiencies include overall station deterioration and the need to increase the number of monitored variables and the number of monitoring stations to fill gaps in the current arrays. The solution to these problems is to replace the vacuum-tube electronics with commercially available, modular, solid state units.

Finally, additional instrumentation (e.g., real-time stack monitoring) are required to have both an accurate knowledge of source terms and environmental concentrations for routine and accidental releases and to provide a basis for controlling emissions to an "as low as reasonable achievable" level.

C. Water Monitoring System Replacement

The existing on-site and off-site monitors and proportional samples need to be reinstrumented because of the obsolete electronics presently used in these systems. Proportional sampling stations are needed to get an accurate sample proportional to flow at a point upstream and downstream of ORNL discharges and where the water is first used for public consumption. These replacements will enable ORNL to comply with DOE Orders.

D. Data Processing and Analysis

Data from radiation and non-radiological monitors will be telemetered for processing, analysis and archiving on a routine or emergency basis. The data processing and analysis system may also serve as a back-up system for ORNL's Waste Operation Control Center and as a predictive tool in the event of an unplanned release.

Additional instrumentation is needed to monitor for non-radiological pollutants.

Modernization of existing liquid and gaseous environmental monitoring stations could be conducted in phases over several years with alternative capital funds; however, implementation of multiple designs, procurement packages and construction contracts as well as integrating separately designed and installed systems would lead to inefficiencies and higher costs. In addition, due to the shortage of General Purpose Plant (GPP) and General Purpose Equipment (GPE) funds, this approach would be difficult to accomplish.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Upgrade environmental monitoring systems
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 85-R-711

9. Purpose, Justification of Need for, and Scope of Project (Continued)

Another alternative is to continue to operate with the present 25 year old systems which, as discussed above, would present increasing operational and maintenance problems; moreover, the inadequacies of the current systems would not be resolved.

10. Details of Cost Estimates*

	Item Cost	Total Cost
a. Engineering, design, and inspection at approximately 12% of construction costs, item b.		$ 350
b. Construction costs		2,800
(1) Data acquisition (including facility adaptation)	$ 1,300	
(2) Special facilities (gaseous effluents)	1,100	
(3) Special facilities (liquids effluents)	400	
Subtotal		$ 3,150
c. Contingency at approximately 12% of above costs		350
Total estimated cost.		$ 3,500

* Estimate based on a completed Conceptual Design Report.

11. Method of Performance

Design and inspection will be by negotiated architect-engineer contract. To the extent feasible, construction and procurement will be accomplished by fixed-price subcontracts and prime contracts awarded on the basis of competitive bidding. The data acquisition system will be specified and procured according to DOE regulations and requirements.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Not Required. TEC is less than $5,000,000.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

Not Required. TEC is less than $5,000,000.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Central chilled water system restoration
Oak Ridge National Laboratory, Tennessee

2. Project No.: 85-R-712

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 1st Qtr. FY 1986

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: None
Date: None

6. Current cost estimate: $ 4,700
Less amount for CP&D: 0
Net cost estimate: $ 4,700
Date: September 1983

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1985	$ 4,700	$ 1,000	$ 1,000	$ 510
1986	0	2,200	2,200	950
1987	0	1,500	1,500	2,240
1988	0	0	0	1,000

8. Brief Physical Description of Project

This project will remove from service three obsolete 600 ton chiller units located in the Central Research and Administration Complex and provide replacement capacity. The Central Compressor Facility structure will be expanded, if required, for the installation of 2,000 ton centrifugal chiller and the associated pumps, controls, and piping. Concurrently, the cooling tower system supplying condenser water to the facility will be upgraded to correct a marginal capacity condition during peak demand periods.

9. Purpose, Justification of Need for, and Scope of Project

The purpose of this project is to: replace three 600 ton chiller units due to age, condition, and limited capacity; increase capacity of a marginal cooling tower system.

The Central Research and Administration Complex consists of seven major facilities with approximately 1,000,000 sq. ft. of floor space and approximately a third of the Laboratories' research personnel. The space is used by multi-discipline groups and supporting service divisions participating in applied and basic research programs.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central chilled water system restoration
Oak Ridge National Laboratory, Tennessee

2. Project No.: 85-R-712

9. Purpose, Justification of Need for, and Scope of Project (continued)

The units to be replaced were obtained from surplus channels in 1952 and are now approximately 35 years old. Their reliability continues to decline, and, in recent years, two of the three machines have been out of service for several weeks or more. Repair parts are no longer stocked by the manufacturer and downtimes are extended by the need to custom fabricate the necessary parts.

The declining reliability of these machines will continue and more frequent interruptions and greater delays to programmatic activities can be anticipated. Many programmatic activities are dependent on computer services and the ORNL Computer Center located in the area served by the 600 ton chillers.

10. Details of Cost Estimate*

	Item Cost	Total Cost
a. Engineering, design, and inspection at approximately 12% of construction costs, item b.		$ 450
b. Construction costs		3,700
(1) Land improvements including grading, landscaping	$ 43	
(2) Building addition (2,500 sq. ft. @ $153/sq. ft.)	362	
(3) Building modifications (concrete work, etc.)	131	
(4) Other structures (cooling tower)	419	
(5) Special facilities (chiller, pumps, piping, etc.)	2,745	
Subtotal		$ 4,150
c. Contingency at approximately 13% of above costs		550
Total estimated cost		$ 4,700

*Cost estimate based on completed conceptual design.

11. Method of Performance

Design and inspection will be on the basis of a negotiated architect-engineer contract. Construction and procurement will be accomplished by fixed-price contracts and subcontracts awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Not required. TEC is less than $5,000,000.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

Not required. TEC is less than $5,000,000.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT-PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Road repair, various locations (ANL, INEL, LBL, RL)

2. Project No.: 84-ER-103

3. Date A-E work initiated: 2nd Qtr. FY 1984

3a. Date physical construction starts: 4th Qtr. FY 1984

4. Date construction ends: 1st Qtr. FY 1987

5. Previous cost estimate: $16,000
Date: August 1982

6. Current cost estimate: $19,500
Less amount of PE&D: 0
Net Cost Estimate: $19,500
Date: June 1984

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1984	$ 19,500[a]	$ 6,500	$ 6,500	$ 737
1985	0	3,750	3,750	6,129
1986	0	4,400	4,400	3,300
1987	0	4,850	4,850	6,334
1988	0	0	0	3,000

8. Brief Physical Description of Project

This project is for the restoration, widening, and improvement of roads at various sites to improve traffic safety and bring these roads into conformance with current standards and practices in highway construction. Brief descriptions of each component, by site, follows:

A. Traffic Safety Improvements, Route 4, Richland, Washington - Approximately six miles of Route 4, the arterial road servicing the Hanford area, will be improved to be more consistent with Washington State highway design guidelines. Each lane will be widened approximately 2 feet to provide standard 12-foot lanes. Shoulder surfaces will be treated and widened to provide the standard design width. Acceleration, deceleration, and holding lanes will be provided where required.

Safety hazards such as poles, fire hydrants, and telephone cable boxes will be removed or relocated as required. Appropriate traffic control devices, lane markers, guard rails, roadway signs, pavement markings, and crash

[a] $3,500,000 reprogrammed from 82-E-306 in FY 1984.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Road repair, various locations (ANL, INEL, LBL, RL)

2. Project No.: 84-ER-103

8. Brief Physical Description of Project (continued)

protection will be provided as necessary. The road shall be resurfaced with an asphalt overlay to eliminate the cracked and uneven places and to match and blend with the additions proposed by this project. The intended useful life of this project is 25 years.

B. INEL Road Refurbishment, Idaho National Engineering Laboratory (INEL), Idaho - This project provides for restoring approximately 37 miles of INEL primary and secondary roads to a safe and reliable condition. The project design will provide an engineered road cross section meeting traffic density and load requirements. Since this is not a total reconstruction project, the repair methods will vary from applying an asphaltic leveling course on the existing surface to demolishing and reconstructing the total road cross section. The work method selected will depend on conditions along the route of each section to be restored. The completed roads will have painted traffic striping, proper crown, adequate surface-thickness, engineered base-course, compacted subgrade and side drainage.

C. Roadwork Project - Safety Program, Lawrence Berkeley Laboratory (LBL), Berkeley, California - This project provides for increasing the radius of curves at various intersections and widening of the main access road to the Laboratory. Vertical and horizontal curves will be removed and roads realigned to conform to the Department of Transportation Highway Design Standard. Included will be separation of pedestrian and vehicular traffic in some areas of the complex.

D. Repair Existing Roads, Argonne National Laboratory (ANL), Argonne, Illinois - This project will reconstruct approximately 10 miles of roadway serving the ANL-East Laboratory site. Included in this reconstruction effort are the main entrance routes to the site and those roads serving the principal permanent buildings and facilities. Roads serving buildings that are to be deactivated will not be reconstructed.

Work to be performed includes:

a. Repair of base course failures
b. Resurfacing with 2-1/2 inch bituminous concrete topping
c. Rework and repair of road shoulders
d. Raising existing manholes to match new road alterations
e. Restriping of traffic lanes and crosswalks
f. Replacement of deteriorated culvert pipes

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Road repair, various locations (ANL, INEL, LBL, RL)
2. Project No.: 84-ER-103

9. Purpose, Justification of Need for, and Scope of Project:

A. Traffic Safety Improvements, Route 4, Richland, Washington - Route 4 is the arterial servicing the Hanford Site. This roadway was built in 1943 prior to formalization of national policies on highway design. Lack of conformance to current highway design guidelines has created serious traffic hazards on the Hanford Site. In addition, Route 4 has deteriorated over the years. The road surface is cracked and uneven, lanes are narrow, and in most places the shoulders are soft, narrow and rutted. The existing lanes are only 10 feet wide, 2 feet narrower than required by current standards. The 10-foot lanes allow very little maneuvering room, and create heavy traffic loads along the road edge. This stress causes pavement edge break-up and hence further reduction of lane width, and deep ruts in the shoulders. These factors have caused increased maintenance and safety problems. This project proposes to improve that portion of Route 4 from the 1100 Area to the gravel pit, a distance of approximately 6 miles. This area carries the greatest amount of traffic and has the highest accident rate.

B. INEL Road Refurbishment, Idaho National Engineering Laboratory (INEL), Idaho - The roads proposed for reconstruction are the sole access to active INEL Facility areas. They have been maintained in continuous use since their original construction during the 1950's and 1960's. Maintenance efforts since that time have included patching, seal coating and surface overlays. Deterioration in the base course and subgrade has progressed to the point that these efforts provide only short term improvement. In addition, pavement edge-breakage has narrowed the road in some sections to less than the minimum required for safe two-lane operation. The current situation has resulted from combinations of the following circumstances:

- Existing roads that were not designed for current traffic density and loads which have led to continuing surface and subsurface breakdown.
- Extreme winter cold temperatures ranging to -40°F causing surface course brittleness and shrinkage leading to extensive cracking, subsequent moisture penetration and subsurface failure.
- High summer temperatures ranging to 100°F causing road weakness in areas of minimum road stability. This results in ruts, depressions and washboards on the road surface.
- Moisture entry through surface cracks and unpaved shoulders. This causes reduced subsurface support strength and surface breaking.
- Frost heave caused by soil capillarity and poor drainage during winter weather. This results in both surface breakup and subsurface failure.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Road repair, various locations (ANL, INEL, LBL, RL) 2. Project No.: 84-ER-103

9. Purpose, Justification of Need for, and Scope of Project (continued)

C. Road Project - Safety Program, Lawrence Berkeley (LBL), Berkeley, California - The existing radius of the curves of the main access road to the laboratory are such that semi-trailers are found to go over the road center line. In some areas of the laboratory pedestrians and vehicles must use the same road way.

Improvement of the laboratory roading and pedestrian systems is required to bring the old substandard roads and sidewalks in the hilly LBL terrain up to acceptable code and safety standards by improving alignment sight distance, removing horizontal and vertical curves, increasing the radius of curves and widening the access road to the site.

This project will be constructed at the Lawrence Berkeley Laboratory which is non-Government owned property.

D. Repair Existing Roads, Phase I, Argonne National Laboratory (ANL), Argonne, Illinois - The site roads are deteriorating at a faster rate than they can be economically repaired. This deterioration reflects the age of the roads, approximately 30 years, and the severity of the climate at the ANL-East site. Failing road edges, the result of base course failures and late winter thaws, cannot be corrected by patching methods. The use of operating funds in an attempt to maintain the roadways in serviceable condition has resulted in unsatisfactory road conditions at best, and a heavy drain on the Laboratory's resources.

A full reconstruction program for those sections of the roadway network which are in worst condition will be provided by this project.

10. Details of Cost Estimate*

	Richland	INEL	LBL	ANL	Total
a. Engineering and design and inspection................	$ 900	$ 535	$ 165	$ 200	$ 1,800
b. Construction costs..................................	6,800	6,110	1,045	1,600	15,555
Subtotal..	7,700	6,645	1,210	1,800	17,355
c. Contingency...	800	955	190	200	2,145
Total estimated cost..............................	$ 8,500	$ 7,600	$ 1,400	$ 2,000	$19,500

*Conceptual Design Reports completed.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Road repair, various locations (ANL, INEL, LBL, RL)

2. Project No.: 84-ER-103

11. Method of Performance

A. RL Subproject - Design and inspection will be accomplished by a negotiated architect-engineering contract or the on-site architect-engineer firm. The major portion of the construction will be accomplished under fixed-price contracts awarded on the basis of competitive bids. Relocation of any power or utility poles will be accomplished through negotiations with the appropriate utility.

B. INEL Subproject - Overall responsibilities for design and construction will be assigned to the INEL prime contractors administered by DOE-ID. The INEL contractor will provide technical direction of the design effort. Construction will be accomplished by fixed price subcontracts awarded on the basis of competitive bidding.

C. LBL Subproject - Design and inspection will be performed under a negotiated architect-engineer contract. To the extent feasible, construction and procurement will be accomplished by fixed-price contracts and subcontract awarded on the basis of competitive bidding.

D. ANL Subproject - Engineering, design and inspection will be performed by Laboratory engineering personnel. Construction will be accomplished by fixed-price contract awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988	Total
a. Total project costs							
1. Total facility costs							
(a) Construction line item..................	$ 0	$ 737	$ 6,129	$ 3,300	$ 6,334	$ 3,000	$19,500
(b) PE&D....................................	0	0	0	0	0	0	0
(c) Expense funded equipment................	0	0	0	0	0	0	0
(d) Inventories.............................	0	0	0	0	0	0	0
Total facility costs..................	$ 0	$ 737	$ 6,129	$ 3,300	$ 6,334	$ 3,000	$19,500
2. Other project costs							
(a) R&D necessary to complete construction..	$ 30	$ 0	$ 0	$ 0	$ 0	$ 0	$ 30
(b) Other project related costs............	0	0	0	0	0	0	0
Total other project funding............	30	0	0	0	0	0	30
Total project costs (1 and 2)...........	$ 30	$ 737	$ 6,129	$ 3,300	$ 6,334	$ 3,000	$19,530

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Road repair, various locations (ANL, INEL, LBL, RL)

2. Project No.: 84-ER-103

12. Funding Schedule of Project Funding and Other Related Funding Requirements (continued)

	Annual Cost
b. Other related annual costs (estimated life of project: 25 years)	
1. Facility operating costs	$ 50
2. Programmatic operating expenses directly related to the facility	0
3. Capital equipment not related to construction but related to the programmatic effort in the facility	0
4. GPP or other construction related to programmatic effort in the facility	0
Total other costs	$ 50

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project costs:
  1. Total Facility:
    a) Construction Line Item
    b) PE&D - No PE&D required.
    c) Expense Funded Equipment - There is no expense funded equipment.
    d) Inventories - There are no inventories required.

  2. Other project funding:
    a) Research and Development is not necessary for this project. The amount shown covers conceptual design activities.
    b) Other Project Related Costs - No other project related costs are anticipated.

b. Total related funding requirements:
  1. These costs are the average maintenance cost of roads at the various sites. They are based on a cost per square foot of new surface escalated to 1987.
  2. Programmatic Operating Expenses - None
  3. Capital Equipment not Related to Construction - None
  4. GPP or Other Construction Related to Programmatic Effort - No GPP funds are required by this project.
  5. Other Costs - No other costs are anticipated.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
MULTIPROGRAM GENERAL PURPOSE FACILITIES
(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: Idaho Engineering Research Laboratory (IERL)
Idaho Laboratory Facility (ILF)
Idaho National Engineering Laboratory (INEL)
Idaho Falls, Idaho

2. Project No.: 80-ES-11

3. Date A-E work initiated: 1st. Qtr. FY 1986

3a. Date physical construction starts: [b]

4. Date construction ends: [b]

5. Previous cost estimate: $ 18,000[a]
Date: August 1980

6. Current cost estimate: $ 19,500[b]
Less FY 1984 PE&D: 0
Net cost estimate $ 19,500[b]
Date: December 1984

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1980	$ 4,000	$ 4,000	$ 4,000	$ 327
1981	4,938	4,938	4,938	2,905
1982	4,000	4,000	4,000	5,651
1983	4,000	4,000	4,000	7,813
1984	1,062	1,062	1,062	1,061
1985	1,500	750	750	993
1986	0	750	750	750

[a] Previous cost estimate includes the first two phases of the Idaho Laboratory, which were completed in FY 1984.

[b] The FY 1986 request provides for architect-engineering work for the third phase, IERL (i.e., detailed design beyond conceptual design). The total estimated cost of this project and exact construction dates are under review.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of Project: Idaho Engineering Research Laboratory (IERL)
Idaho Laboratory Facility (IRF)
Idaho National Engineering Laboratory (INEL)
Idaho Falls, Idaho

2. Project No.: 80-ES-11

8. Brief Physical Description of Project

The Idaho Engineering Research Laboratory (IERL) is the third phase of the Idaho Laboratory Facility (ILF) which currently consists of offices and scientific laboratories for basic bench scale research. The IERL is an essential and integral portion of the original ILF concept of consolidating scattered research activities into one multi-disciplinary modern complex that will enhance INEL's capabilities to perform ongoing and planned scientific and engineering research in a cost effective manner. The IERL will provide for the continuation and extension of bench scale research performed in the science laboratories to proof-of-principal or scale up research. The IERL will contain laboratories for Materials Process Engineering, Thermal Plasma Engineering, Chemical Engineering and Structural Engineering; will house a multipurpose, high-bay Engineering Experiments Laboratory; and will provide administrative and engineering support areas.

The IERL will be built adjacent to or adjoined to the ILF Laboratory and Office buildings and will provide five to seven large open laboratory areas as well as administrative, storage and engineering support areas in a mezzanine over a portion of these laboratory areas. The main building will be constructed with structural steel framing, insulated metal wall panels and built-up ply roof. The ceiling height will be 20-25 feet in all areas but the Engineering Experiments and Structural Engineering Laboratories, where the ceiling height will reach 35 feet in order to provide for overhead cranes. A heavily reinforced floor will be provided in the high bay areas to accommodate experiments requiring large equipment.

All areas in the IERL will be provided with fire protection. Utilities required include water, electrical power, compressed air and inert gas supplies. Necessary laboratory equipment includes several types of welding machines, furnaces, lathes, mills, grinders, an emission spectrograph, an optical analyzer and laser holography system.

In keeping with the overall mission of the INEL as an engineering laboratory, it is anticipated that proof-of-principle engineering research will significantly increase in the near future. Long term basic engineering research projects are currently being initiated in support of Basic Energy Sciences (BES) within the Office of Energy Research. It is anticipated that these projects will continue to grow in conjunction with forecasted growth in this area by BES.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Idaho Engineering Research Laboratory (IERL)
Idaho Laboratory Facility (ILF)
Idaho National Engineering Laboratory (INEL)
Idaho Falls, Idaho

2. Project No.: 80-ES-11

9. Purpose, Justification of Need for, and Scope of Project

Engineering research in overall support of fusion engineering, waste management development, reactor safety research, conservation R&D, and other major INEL programs is estimated to continue at current levels. Furthermore, support for this type of research from other agencies such as DOD and DOI is expected to grow, especially with the DOI (Bureau of Mines) research project on strategic and critical materials.

Currently much of INEL engineering research is conducted in a limited fashion in scattered site facilities. These facilities are separated by as much as 40-50 miles. Personnel involved in more than one project often must travel between facilities, which requires separate transportation in many cases and the loss of up to one-half day in available time. Research facilities at the site are often old, retrofitted, energy inefficient buildings that are expensive to modify or cannot be modified to meaningfully accommodate some equipment or scaled-up engineering research experiments. The existing new scientific research Laboratory at the ILF complex can accommodate some engineering research, but space, power, and ventilation requirements preclude effective scale-up (proof-of-principle) experiments; these must now be located elsewhere at the Site.

On the basis of 250 feet per person, laboratory space requirements for known programs currently exceed 50,000 square feet. Much of the laboratory space currently in use is inadequate. Some space is located in facilities which are abandoned radioactive reactor areas. These areas were constructed during the 1950's and lack the cleanliness, noise suppression, and environmental controls critical to laboratory programs. Moreover, radioactive contamination can invalidate test results, and efforts to modify existing spaces frequently result in greater contamination problems. Temperature variations, which should be less than 3^oF for reliable testing, vary from below freezing in the winter to 120^oF in the summer. Summer cooling is accomplished with outside air, resulting in frequent problems with sand and dust. Furthermore, existing overcrowded laboratories promote schedule delays and poor experiment reliability due to over-expended capacity and unavoidable cleanliness control problems.

The Materials Process Engineering Laboratory will provide for advanced ceramic processing, rapidly solidified alloy production, fracture/failure mechanics, nondestructive evaluation systems testing, automated welding research, and metals melting and casting.

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: Idaho Engineering Research Laboratory (IERL),
Idaho Laboratory Facility (ILF)
Idaho National Engineering Laboratory (INEL)
Idaho Falls, Idaho

2. Project No.: 80-ES-11

---

9. Purpose, Justification of Need for, and Scope of Project (continued)

The Thermal Plasma Engineering Laboratory will provide for investigation of plasmas in extractive metallurgy, fine powder production, novel alloy syntheses, and surface modification support diagnostic techniques.

The Chemical Engineering Laboratory will accommodate such chemical process research as combustion research, high temperature chemistry, hydrocarbon processing, and chemical separations; such thermal fluids research as multiphase flow, compressible flow, energy storage and phase change research; and such aerosol research as aerosol production, transport mechanisms and control techniques.

The Structural Engineering Laboratory will provide primarily for vibration tests to determine the dynamic response of larger structures and components including equipment to seismic and dynamic load environments. It will also provide equipment to conduct high load uniaxial tensile testing studies on larger flawed specimens.

The Engineering Experiments Laboratory will be a high bay laboratory facility for various scaled-up experiments arising from any of the other engineering research programs. It will include 35 ft. or higher ceilings, spectal power, overhead cranes, and other features to provide a facility that will be readily adaptable for a wide variety of limited-duration engineering scale-up experiments. The types of work that would be performed in this facility include proof of concept chemical and materials processing, large scale combustion and thermal fluids experiments, and advanced industrial processing pilot experiments.

Failure or delay in funding the IERL facility will seriously impede the INEL's capabilities to fulfill contracted or planned engineering research for DOE, NRC, DOI, and others. Major impacts include:

1. Loss or delay in obtaining a consolidated modern complex and equipment to enable INEL to perform top quality advanced engineering research development.
2. Reduced capability in some areas of research since some equipment required is not compatible with existing facilities.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Idaho Engineering Research Laboratory (IERL) Project No. 80-ES-11
Idaho Laboratory Facility (ILF)
Idaho National Engineering Laboratory (INEL)
Idaho Falls, Idaho

9. Purpose, Justification of Need for, and Scope of Project (continued)

3. Reduced output from personnel involved in both scientific and engineering research efforts due to travel time between scattered facilities. Travel time now amounts to 30% of available weekly work time.
4. High cost to DOE to maintain energy inefficient buildings, additional motor vehicles for travel between facilities, etc.
5. High costs to programs to modify and renovate inadequate facilities to accommodate new equipment and/or proof-of-principle experiments.
6. Reduced research quality as personnel "make do" with older equipment.
7. Loss of performance on programs due to unavailability of adequate facilities and/or equipment.
8. Delays and backlog of scale-up engineering research from scientific laboratories as facilities are sought and made available.
9. Loss of top research personnel and inability to hire top candidates who require high quality facilities.

10. Details of Cost Estimate

The project provides funds for architect-engineering work and detailed design beyond conceptual design during FY 1986. It is anticipated that the TEC will be $20,000,000 to $25,000,000.

11. Method of Performance

Design will be performed by an outside A-E firm.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Not required.

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

Not required.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
ENVIRONMENTAL COMPLIANCE PROGRAM
(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

3. Date A-E work initiated: 1st Qtr. FY 1985

3a. Date physical construction starts: 2nd Qtr FY 1986

4. Date construction ends: 4th Qtr. FY 1988

5. Previous cost estimate: None
Date:

6. Current cost estimate: $5,000
Less FY 1984 PE&D: 0
Net cost estimate $5,000
Date: December 1984

7. **Financial Schedule:**

		Costs			
Fiscal Year	Obligations	FY 1984	FY 1985	FY 1986	After FY 1986
1986	5,000	0	0	2,500	2,500

8. **Brief Physical Description of Project**

These projects provide for the many miscellaneous alterations, additions, modifications, replacements, and non-major new construction items required to reduce or eliminate environmentally harmful discharges from ORNL.

Upgrade Process Waste Systems

o Pre-treatment of process waste at selected sites.. $ 950

Project will provide isolation systems, collection and equalization systems, treatment systems (such as clarification, biological oxidation, filtration, ozonation, carbon absorption, and neutralization) and monitoring for 7000, 7600, 6000, 7900, 3004 areas and other remote areas. Examples of systems are pH adjustments, solid removal and other pollutant treatment.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

8. Brief Physical Description of Project (continued)

Improve Sewage Treatment Plant and Sanitary Sewage System

o Improvements to Sewage Collection System for 7900 Area (HFIR/TRU).................................. $ 250

Sanitary sewage generated in the 7900 area is routed to a central collection basin. From there, it is hauled by tanker truck to ORNL's main Sewage Treatment Plant. The amount of sewage being hauled is much larger than the amount attributable to the area's population. This extra flow is caused mainly by inflow/infiltration. Also, the collection basin may be leaking. This project proposes to rehabilitate the sewer drainage system where needed and to replace the collection facility.

Upgrade the Storm Sewer System

o Improve collection and containment systems, Phase I.. $ 900

To address the areas of leakage of wastes at ORNL, the various transfer lines for process wastewater and sewage drainage must be upgraded. The upgrade of these lines may involve lining or replacement as required. To address the requirements for spill control, ORNL must upgrade the containment of all areas handling hazardous or toxic materials. This includes diking, curbing, collection systems, etc. To address problems with runoff, ORNL must rework and upgrade certain areas where the runoff is determined to contain toxic or hazardous pollutants. This project will also specifically address containment and spill prevention of oil.

Characterize and Improve Known Hazardous/Toxic/Radiological Spill Sites

o Mercury Collection System, Phase I.. $ 920

Rehabilitate pipelines that have inflow/infiltration problems in areas where there are sources of mercury. The most cost-effective and legally-acceptable method for treatment of the mercury-contaminated wastewater will be utilized. This may involve a system which would consist of a separate network of pumping stations and piping to transfer the wastewater to a dedicated mercury treatment process.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

8. Brief Physical Description of Project: (Continued)

Improve Management of Hazardous and Toxic Materials

o Replacement of PCB Transformers, Phase I.. $ 700

Drain PCB transformers, dispose of dielectric fluids from these transformers, dispose of drained transformer and replace with non-PCB transformers.

o Non-Radiological Waste Volume Facility (glass, drum and scintillation vial crusher facilities....... $ 330

Provide a facility for glass, drum and scintillation vial crushers.

o Modular Cement Batch Plant.. $ 950

The mobile batch plant is a self-contained system that includes cement and aggregate batchers that deliver accurately batched materials. The unit is prepiped, prewired, and tested, ready for immediate on-site installation. Water and power hookups are required at the site. Cement storage units, folding aggregate bins, scales, and batchers are installed on a single frame. The frame is designed to be towed as a semi-trailer. A cement storage unit which is vented and equipped for air loading of bulk cement is provided. Minimum foundation work is required for the batch plant. A small poured slab is required for the foundation of a tilt mixer.

9. Purpose, Justification of Need for, and Scope of Project

o Pre-treatment of process waste at selected sites

As authorized by Section 304(e) of the Clean Water Act, the Federal Code of Regulations specifically addresses the control of runoff, spillage and leakage of hazardous and toxic pollutants (40 CFR 125.100). Industries who handle and discharge any toxic pollutants or hazardous pollutants are subject to requirements relative to all activities which may result in significant amounts of pollutants reaching the waters of the United States. In addition, 40 CFR 125.103 states that best management practices shall be expressly incorporated into a National Pollutant Discharge Elimination System (NPDES) permit. To address the areas of leakage of wastes at ORNL, the various

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

---

9. Purpose, Justification of Need for, and Scope of Project

transfer lines for process wastewater and sewage drainage must be upgraded. The upgrade of these lines may involve lining or replacement as required. In addition, collection and treatment systems must be provided for remote areas of ORNL.

For oil pollution prevention, 40 CFR 112.3 establishes the requirements for a Spill Prevention Control and Countermeasures (SPCC) Plan. In Section 40 CFR 112.7 guidelines for the preparation and implementation of a SPCC plan are presented. These guidelines require, as a minimum, that dikes, curbing and drainage systems be provided for on-shore facilities. To address this area of the regulations, ORNL must upgrade numerous facilities which handle oil and related products. This will provide isolation, collection and treatment (e.g., process modifications to reduce nitrates) systems for chemical discharges into streams.

o Improvements to Sewage Collection System for 7900 Area (HFIR/TRU)

Regulations in 40 CFR 125.103 state that best management practices shall be expressly incorporated into a National Pollutant Discharge Elimination System (NPDES) permit. To ensure that best management practices are employed in the collection of sewage for treatment at ORNL's Sewage Treatment Plant, efforts must be made to eliminate non-sanitary drainage from the system. Currently, the major source of non-sanitary drainage for the 7900 area is the result of inflow/infiltration. Therefore, to address the areas of inflow/infiltration of non-sanitary drainage at this area, the various transfer lines for sewage drainage must be upgraded. The upgrade of these lines may involve lining or replacement as required. Therefore, the scope of this project is to line pipes and replace sewage collection basin.

o Improve collection and containment systems, Phase I

Under the "Best Management Practices" of the Clean Water Act Section 304 (e), the regulations specifically address the control of runoff, spillage and leakage of hazardous and toxic pollutants (40 CFR 125.100). Facilities who handle and discharge any toxic pollutants or hazardous pollutants are subject to requirements relative to all

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

---

9. Purpose, Justification of Need for and Scope of Project (continued)

activities which may result in significant amounts of pollutants reaching the waters of the United States. For oil pollution prevention, 40 CFR 112.3 establishes the requirements for a Spill Prevention Control and Countermeasures (SPCC) plan. This SPCC plan is specifically required to address the areas covered by the scope of this project, which are to line the lines, provide diking and curbing and collection systems.

- Mercury Collection System, Phase I

During operations at ORNL, mercury was spilled in certain areas of the plant. The current discharge of mercury from certain areas is as high as 0.029 mg/L while the Clean Water Act's BAT level is 0.008 mg/L. To meet these BAT discharge limits, the drainage from certain areas where spills occurred should have all piping cleaned out or removed and some type of mercury collection system installed. This would eliminate the major sources of mercury discharges and allow ORNL to meet the State and EPA discharge limits. The scope of this project provides isolation, collection and treatment (e.g., mercury removal ion exchange resins) systems for mercury before discharges are made into streams.

- Replacement of PCB Transformers, Phase I

ORNL uses many transformers which use polychlorinated biphenyls (PCBs) as their dielectric fluid. A number of these transformers are located in areas where spills or leaks of the PCBs could easily reach the environment. This project proposes either to replace PCB transformers with new units or to treat the dielectric fluid (>1000 ppm) chemically to destroy the PCBs it contains. Many of these transformers are reaching operational life and beginning to leak. The approach taken for each transformer will be on a priority basis and the most cost-effective way to remove and to dispose of the PCB material will be used. Toxic Substance Control Act (TOSCA) regulations found in 40 CFR, Part 761.30 require that if a PCB transformer is found to have a leak which results in any quantity of PCB's running off or about to run off the external surface of the transformer, it must be repaired or replaced. Also any servicing of PCB transformer coils from the transformer casing is prohibited. The scope of the project is to drain PCB transformers, dispose of dielectric fluids from these transformers, dispose of drained transformers, and replace with non-PCB transformers.

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

---

9. Purpose, Justification of Need for and Scope of Project (continued)

- Non-Radiological Waste Volume Reduction Facility (Glass, Drum and Scintillation Vial Crusher Facilities)

Regulations in 40 CFR 165.9, "Recommended Procedures for the Disposal of Pesticide Containers and Residues," allow for the disposal of empty pesticide containers which have been triple-rinsed, to be disposed of in an industrial landfill. Also containers which have contained hazardous materials/wastes and meet the definition of empty under Rule 1200-1-11.02(1)(g) of Rules Governing Hazardous Waste Management in Tennessee, can be disposed in an industrial landfill. Compaction and disposal of these metal containers will extend the life of the landfill facility by volume reduction and will decrease costs for commercial disposal of the containers as hazardous waste.

Glass is a physical agent that can be harmful. The Tennessee Code Annotated, Title 50: Occupational Safety and Health, Section 50-3-203 requires measures to protect employees from hazards including harmful physical agents. Compliance with paragraph (b) requires, "Control techniques or technological procedures be used, in connection with such hazards." Also in compliance with the Tennessee Regulations Governing Solid Waste Processing and Disposal, the connection with the Tennessee Solid Waste Disposal Act, Rule 1200-1-7-.05, item 6 of paragraph (2)(a), operational procedures, which must be submitted to the Tennessee Department of Health and Environment, to include accident prevention procedures. This will provide a facility with three areas to house glass, drums, and scintillation vial crushers.

- Modular Cement Batch Plant

ORNL has over forty hazardous waste sites where soil or sediment contains hazardous materials. Cleanup and disposal of these soils, sediments and sludges is a difficult problem. In order to alleviate the cleanup and disposal problem, a cement batch plant is being proposed which can solidify the soil, sediment and sludge in a specifically designed grout. By reducing the leaching potential of the soil, sediment, and sludge, the solidified material could be disposed of as nonhazardous waste.

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: General plant projects
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-800

---

10. Details of Cost Estimate:

The estimated costs are preliminary and, in general indicate the magnitude of each program. These costs included engineering, design, construction and inspection.

11. Method of Performance:

Design will be on the basis of negotiated architect-engineer contracts. To the extent feasible, construction and procurement will be accomplished by firm fixed-price contracts and subcontracts awarded on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
ENERGY SUPPLY RESEARCH AND DEVELOPMENT - PLANT AND CAPITAL EQUIPMENT
MULTIPROGRAM LABORATORIES FACILITIES SUPPORT
ENVIRONMENTAL COMPLIANCE PROGRAM
(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: Non-radiological process waste treatment project (design only)
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-801

---

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: TBD

4. Date construction ends: TBD

5. Previous cost estimate: None
Date:

6. Current cost estimate: $3,000*
Less FY 1984 PE&D: 0
Net cost estimate $3,000
Date: December 1984

---

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1986	$ 3,000	$ 3,000	$ 3,000	$ 3,000

8. Brief Physical Description of Project

A Non-Radiological Wastewater Treatment Project (NRWTP) is proposed for the Oak Ridge National Laboratory (ORNL) that will address regulatory environmental compliance concerns. Among these concerns are certain non-radiological process waste streams which are currently discharged untreated into area creeks. This project proposes to collect and treat these streams as required to meet discharge parameters as established by the Environmental Protection Agency (EPA) and the State of Tennessee. The NRWTP will provide required collection, treatment, and monitoring facilities based on ongoing wastewater characterization studies, treatability studies, and ultimate effluent criteria established by regulatory agencies.

*This budget request is intended to provide funds for Title I and II Engineering Design in FY 1986. The Conceptual Design Report to be completed by March 31, 1985 will provide a definition of the total Title I and II Engineering cost as well as the total estimated cost of the project. The estimated cost of the complete project, based on a Feasibility Study completed in September 1984, is $23,000,000. The Feasibility Study identified a number of factors and possible design alternatives which could affect the overall cost of the project. The Conceptual Design Report will resolve these uncertainties. Because of the urgency of eliminating discharges which do meet established regulations, the Department has decided to initiate the project immediately

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Non-radiological process
waste treatment project (design only)
Oak Ridge National Laboratory
Oak Ridge, Tennessee

2. Project No.: 86-R-801

8. Brief Physical Description of Project: (Continued)

Several processes to be considered in treating these waste streams are classification, filtration, carbon absorption, reverse osmosis, evaporation, and ion exchange as well as other processes to meet specific needs. Physical construction will include pumps and piping to transfer wastewater to a central and/or satellite treatment facilities, special equipment to accomplish the desired handling and treatment of wastewater and resultant solid waste, computerized monitoring and control equipment, and new buildings to house equipment and support facilities.

Various options for addressing degree of centralization and facility siting will be investigated in the Conceptual Design scheduled for the first and second quarters of FY 1985. The project includes a National Pollutant Discharge Elimination System (NPDES) monitoring station for the treated effluent.

9. Purpose, Justification of Need for, and Scope of Project:

The purpose of the proposed project is to collect and treat the effluent streams from ORNL facilities including the Process Waste Treatment Plant (Building 3544), Central Research and Administration (4500 Area), Environmental Sciences Laboratory (Building 1505), Radioisotope Production Laboratories (3000 Area, non-radiological effluents), various flows from Melton Valley (High-Flux Isotope Reactor and the Transuranium Processing Plant, non-radiological effluents), and other waste streams so that they will meet water quality parameters. The parameters now exceeded by these streams include organic matter, dissolved solids, nitrates, and several heavy metals.

ORNL's new State of Tennessee NPDES permit will include a compliance schedule for the achievement of the "best available technology economically achievable" (BATEA) criteria as required by the Clean Water Act. ORNL currently has several discharges which do not meet water quality limits. Therefore, to meet the NPDES discharge limits, as required by the Clean Water Act and Executive Order 12088, ORNL's effluents must be provided with the treatment proposed by this project. A major stream, the effluent from Building 3544, is currently being treated by ion exchange to remove only radioactivity but has exceeded NPDES limits in several parameters (dissolved solids, chemical oxygen demand (COD), and nitrates). Other streams are not currently treated and surpass the NPDES requirements and must be treated. The current waste treatment plant (Building 3544), even with modifications, does not have the capability to treat all exceeded parameters, and is designed for a lower feed rate than will be required to treat the combined feed streams. Therefore, it is necessary to build a new wastewater treatment system with the capability to treat these streams.

CONSTRUCTION PROJECT DATA SHEETS

---

1. Title and location of project: Non-radiological process
   waste treatment project (design only)
   Oak Ridge National Laboratory
   Oak Ridge, Tennessee

2. Project No.: 86-R-801

---

9. Purpose, Justification of Need for, and Scope of Project (continued)

The purpose of this project is to resolve the major environmental concerns at ORNL with respect to the discharge of non-radiological process wastewater. Certain untreated discharges are not in compliance with the Clean Water Act and the Tennessee Water Quality Act and the Tennessee Water Quality Act. A new National Pollutant Discharge Elimination System (NPDES) permit will be issued by the EPA and state which will identify as many as 25 monitoring points within the ORNL boundaries. The permit will require that all process waste be treated and there is currently no means of treatment for many of these streams. This project will provide this treatment which will ensure ORNL's compliance with discharge parameters to be established.

The EPA is currently negotiating with DOE to establish a schedule by which compliance with the NPDES permit will be accomplished. Deferral of this project will not allow ORNL to complete construction in FY 1989 which is needed to meet the compliance schedule.

10. Details of Cost Estimate:

The project provides funds for an Architect-Engineer to accomplish Title I and II design during FY 1986. Early studies are in progress and a Conceptual Design Report will be issued by March 31, 1985, at an estimated cost of $500,000. The Conceptual Design will confirm the total estimated cost for the project.

11. Method of Performance:

Design will be performed under negotiated architect-engineer contract and by the Operating Contractor.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

Information pertinent to Item 12 regarding schedule and narrative explanation of total project funding and other related funding will be provided upon completion of the Conceptual Design Report in March 1985.

13. Narrative Explanation of Funding Schedule:

Information pertinent to Item 13 regarding schedule and narrative explanation of total project funding and other related funding will be provided upon completion of the Conceptual Design Report in March 1985.

DEPARTMENT OF ENERGY
FISCAL YEAR 1986 CONGRESSIONAL BUDGET REQUEST
GENERAL SCIENCE AND RESEARCH
VOLUME 4
TABLE OF CONTENTS

Appropriation Language 19

Summary of Estimates by Major Activities 20

Program Overview 21

High Energy Physics 27

Nuclear Physics 81

General Science Program Direction 107

DEPARTMENT OF ENERGY

Proposed Appropriation Language

General Science and Research Activities

For expenses of the Department of Energy activities including the purchase, construction and acquisition of plant and capital equipment and other expenses incidental thereto necessary for general science and research activities in carrying out the purposes of the Department of Energy Organization Act (Public Law 95-91), including the acquisition or condemnation of any real property or facility or for plant or facility acquisition, construction, or expansion; purchase of passenger motor vehicles (not to exceed [4] 13 for replacement only); [$726,905,000] $685,400,000, to remain available until expended. (Public Law 98-360, making appropriations for energy and water development, 1985.)

DEPARTMENT OF ENERGY
FISCAL YEAR 1986 CONGRESSIONAL BUDGET REQUEST
SUMMARY OF ESTIMATES BY APPROPRIATION BY MAJOR ACTIVITY
GENERAL SCIENCE AND RESEARCH
BUDGET AUTHORITY IN THOUSANDS OF DOLLARS

	FY 1984 Actual	FY 1985 Estimate	FY 1986 Request
High Energy Physics	472,947	545,629	510,100
Nuclear Physics	163,220	182,863	172,900
High Energy and Nuclear Physics Program Direction	2,250	2,175	2,400
Subtotal, General Science and Research	638,417	730,667	685,400
Addback of Proposed Rescission	---	38	---
Savings from Management Initiatives.	---	-700	---
Total, General Science and Research.	638,417	730,005	685,400

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
PROGRAM OVERVIEW

High Energy and Nuclear Physics

The Department's General Science programs are concerned with basic research to discover and understand the fundamental constituents of matter and energy and the basic forces in nature. Understanding of the laws of nature and the basic components from which matter and energy, in all their varied forms are composed, forms the foundation upon which all of modern science and technology rests. Deeper understanding correspondingly contributes, sometimes in spectacular ways, to all of the scientific disciplines and to our Nation's technological base. History has shown that this type of basic research has significant long-term benefits, e.g., the discovery of both fission and fusion of nuclei resulted from the kind of basic research undertaken in these programs earlier in the century. The Department, along with its predecessor agencies, has a history of effectively managing and operating the large, high technology facilities and research activities which characterize high energy physics and nuclear physics. The Department serves as the lead agency for these programs.

The Department's General Science programs are organized into two interrelated scientific programs, High Energy Physics and Nuclear Physics. While these programs are not directly associated with energy technology in the near or mid-term, they support basic research whose aim is to provide new knowledge which is expected to have long-term scientific and technological impacts on energy development and utilization and on other aspects of our society. The salaries, benefits and associated costs of the staff of the High Energy Physics and Nuclear Physics programs are also included in the General Science category as a separate program, called General Science Program Direction.

Matter is made up of substances known as the chemical elements. The smallest distinguishable unit of an element is the atom. Within the atom, there is a central part called the nucleus which contains most of the mass of the atom. The constituents of the nucleus are neutrons, protons, and mesons which in turn are now believed to be made up of more elementary particles, called quarks. The Nuclear Physics program strives to attain an understanding of the structure and properties of atomic nuclei and the forces governing their motion and interactions at the most elementary level possible. The High Energy Physics program is an exploratory field of basic research which strives to reach the ultimate description of matter and energy through discovering and studying the properties of the most basic constituent building blocks of matter (such as quarks), the nature and relationship of the four known basic forces acting among them, and the most elemental transformations between energy and matter. In recent years outstanding progress has been made toward the unification of the forces of nature and toward understanding the ultimate structure of matter in terms of basic constituent quarks and leptons. In achieving these levels of knowledge, United States high energy physicists have won or shared in three Nobel prizes during the last six years.

A major current objective of High Energy Physics is the unification of the basic forces into a single comprehensive theoretical framework. Part of the recent great progress in science has been a reduction in the apparent number of basic forces through the conceptual unification of the weak nuclear and electromagnetic forces into a single force -- the electroweak force. The recent experimental evidence for the existence of the W and Z^0 particles, together with experimental discoveries during the past decade of neutral weak currents and of particles with charmed quark and even heavier quark constituents, confirm this conceptual unification. The electromagnetic and weak nuclear forces can now be viewed in a natural way as different aspects of one electroweak force. There is now increasing anticipation that the unification of the strong nuclear and electroweak forces into one "grand unified" force may be possible, thereby reducing the apparent number of basic forces in nature to only two. The goal is eventually to incorporate the gravitational force into a super-grand unification scheme, which would bring all of the basic forces into a single unified framework. Exactly what will follow from the various stages of unification cannot be predicted in any detail, however, one can certainly anticipate profound and practical impacts analogous to those which followed the unification of electricity and magnetism by Maxwell late in the 19th century, and the unification of matter and energy by Einstein early in this century. The basic experimental technique used is to study the results of violent collisions of very high energy particles with fixed targets or with other particle or antiparticle beams. In these collisions many entirely new forms of matter can be produced in an energy/matter interchange, and the study of the interactions reveals properties of the underlying building blocks and basic forces involved.

The Nuclear Physics program is a comprehensive program of interdependent experimental and theoretical investigations of atomic nuclei. The program's goals include an understanding of the fundamental forces of nature by using nuclei as a proving ground. As is the case with High Energy Physics, the Nuclear Physics program depends upon the operation of large and complicated accelerator facilities which provide a variety of projectile beams required for forefront nuclear research. Not only are the experimental and theoretical tools similar, but also the progress in the two field interact synergistically. For example, developments in understanding of the laws of nature and theoretical projections have led to development of a new theoretical framework, quantum chromodynamics (QCD), which promises to allow understanding of the strong nuclear force on a fundamental basis. Experiments in nuclei will allow tests of these theoretical developments and will provide guidance for future development of the theory.

The General Science programs support a few large accelerator and colliding beam facilities which are available to all qualified scientists on the basis of the merit of their scientific proposals. Approximately 75% of the research in high energy physics is done by collaborative groups of university-based and/or laboratory scientists. Proposals from university and laboratory user groups for accelerator research time are evaluated by laboratory scientific program advisory committees which recommend those proposals with the greatest scientific promise. The High Energy Physics program operates almost exclusively in this mode, while Nuclear Physics, in addition to national facilities, also supports dedicated accelerator facilities located on the campuses of four leading universities. To complement, interpret, and guide the experimental work, each program supports a vigorous theoretical research effort at universities and at the national laboratories.

The FY 1986 High Energy Physics budget request addresses the funding requirements for a facility utilization level in the 45-50 percent range; for meeting the highest priority needs for the initial complement of detectors for Tevatron at Fermilab and SLC at SLAC; for completion of the Tevatron I and SLC construction projects; for upgrading the central computing capability at Fermilab to handle the Tevatron data; and for continuation of advanced accelerator technology R&D.

A major feature of the High Energy Physics program in FY 1986 will be the operation of the Tevatron superconducting synchrotron at Fermilab for fixed-target experiments near the 1000 GeV energy range and pre-operating tests of the proton-antiproton colliding beam capability provided by Tevatron I. The program will also include operation and research utilization of the AGS at Brookhaven National Laboratory with its new unique high energy polarized proton beam, and the operation of PEP, and pre-operating systems tests of the SLC. The request provides support for participation by university based groups in experimental research including accelerator user group efforts and non-accelerator experiments, and for theoretical research efforts. The FY 1986 program also includes funding for continuation of advanced technology research and development, including R&D studies related to the next generation hadron-hadron collider (Superconducting Super Collider, SSC).

The FY 1986 High Energy Physics capital equipment request provides a small increase above the FY 1985 level in order to help meet the highest priority needs associated with the initial complement of detectors and secondary beams to implement the research programs using the major new capabilities being provided by the Tevatron I proton-antiproton collider at Fermilab and by the SLC electron-positron collider at SLAC. The equipment request for FY 1986 is essential for effective utilization of the new U.S. High Energy Physics facilities being completed in FY 1985 and FY 1986 at Fermilab and SLAC. Implementation of the research programs at these new facilities without undue delay is critical to the strength of the U.S. High Energy Physics program for the remainder of the 1980's.

The FY 1986 Nuclear Physics budget request addresses the funding requirements to provide overall utilization of the national accelerator facilities of about 45 percent and provides for initiation of heavy ion nuclear research and accelerator operations at the Alternating Gradient Synchroton (AGS) at BNL. The Tandem/AGS Heavy Ion Transfer Line, upon completion in FY 1986 will provide heavy ion beams to the AGS for acceleration to energies of 14 billion electron volts per atomic mass unit (GeV/AMU) for atomic nuclei up to mass 32 (sulfur). This capability will be unique in the world and will offer the possibility that for the first time scientists may be able to create exotic new states of nuclear matter which have never before been observed in the laboratory.

An important component of the FY 1986 Nuclear Physics program is the continuation of accelerator R&D and architect and engineering activities to better define the Continuous Electron Beam Accelerator Facility (CEBAF) project's scope, schedule and total cost. The objective of the FY 1986 work is establishment of a technical base for this project so construction could be initiated in FY 1987. CEBAF will be a major facility centering on an electron linear accelerator/stretcher ring complex capable of delivering intense, continuous beams in the energy range from 500 to 4,000 MeV. The intensity of the beam in combination with multi-GeV energy and unique high duty factor will make this facility unmatched in the world. The facility will have the capability of addressing a crucial class of problems facing nuclear physics today, namely the understanding of the relationship between the traditional and emerging descriptions of nuclear dynamics. The aim is to synthesize into a unified description the traditional picture of nuclei--based on nuclear, meson, and isobar degrees of freedom--and the emerging view of an underlying structure of quarks and gluons.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
PROGRAM OVERVIEW
HIGH ENERGY AND NUCLEAR PHYSICS
GENERAL SCIENCE AND RESEARCH

(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
High Energy Physics				
Physics Research				
Operating Expenses.....	$ 99,500	$107,494	$107,494	$111,300
Subtotal...........	99,500	107,494	107,494	111,300
Facility Operations				
Operating Expenses.....	158,947	175,235	175,235	187,800
Capital Equipment......	51,500	58,700	58,700	63,100
Construction...........	81,000[a]	114,000	114,000	55,500
Subtotal...........	291,447	347,935	347,935	306,400
High Energy Technology				
Operating Expenses.....	82,000	90,200	90,200	92,400
Subtotal...........	82,000	90,200	90,200	92,400
Total				
Operating Expenses.....	340,447	372,929	372,929	391,500
Capital Equipment......	51,500	58,700	58,700	63,100
Construction...........	81,000	114,000	114,000	55,500
High Energy Physics......	$472,947	$545,629	$545,629	$510,100
Nuclear Physics				
Medium Energy Nuclear Physics				
Operating Expenses.....	$ 64,634[b]	$ 74,615[b]	$ 74,615[b]	$ 76,450
Subtotal...........	64,634	74,615	74,615	76,450
Heavy Ion Nuclear Physics				
Operating Expenses.....	46,773	49,448	49,448	52,650
Subtotal...........	46,773	49,448	49,448	52,650
Low Energy Nuclear Physics				
Operating Expenses.....	12,867	13,500	13,500	13,400
Subtotal...........	12,867	13,500	13,500	13,400
Nuclear Theory				
Operating Expenses.....	8,946	9,300	9,300	9,400
Subtotal...........	8,946	9,300	9,300	9,400
Capital Equipment.......	11,300	12,700	12,700	14,000
Construction............	18,700[a]	23,300	23,300	7,000
Total				
Operating Expenses.....	133,220	146,863	146,863	151,900
Capital Equipment......	11,300	12,700	12,700	14,000
Construction...........	18,700	23,300	23,300	7,000
Nuclear Physics..........	$163,220	$182,863	$182,863	$172,900

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
General Science Program Direction				
Operating Expenses.....	$ 2,250	$ 2,175	$ 2,175	$ 2,400
Program Direction........	2,250	2,175	2,175	2,400
Total				
Operating Expenses.....	475,917	521,967	521,967	545,800
Capital Equipment......	62,800	71,400	71,400	77,100
Construction..........	99,700	137,300	137,300	62,500
Subtotal General Science and Research...........	638,417	730,667	730,667	685,400
Savings from FY 1984 Initiatives............	0	- 700	- 700	0
General Science and Research...............	$638,417[c]	$729,967[d][e]	$729,967[d][e]	$685,400[f]
Staffing Total FTE's.....	34	39	39	39

Authorization: Section 209, P.L. 95-91

---

[a] Reflects $5,000,000 transferred from High Energy Physics ISABELLE/CBA construction project to Nuclear Physics.

[b] Includes $3,000,000 in FY 1984 and $3,100,000 in FY 1985 Defense Programs support of LAMPF operations.

[c] Does not include $2,833,000 transferred to the Energy Supply Research and Development Appropriation for use in accordance with the Small Business Innovation Development Act of 1982, P. L. 97-219.

[d] FY 1985 total reflects a reduction of $5,300,000 for Management Initiative Savings other than IG audits/deogligations contained in the FY 1985 President's Request.

[e] FY 1985 total reflects a reduction of $3,000,000 for ADP general reduction and savings of $38,000 for Section 2901 of the Deficit Reduction Act of 1984 (P.L. 98-369).

[f] FY 1986 total reflects a reduction of $10,015,000 for FY 1986 Management Initiative Savings.

DEPARTMENT OF ENERGY
FISCAL YEAR 1986 CONGRESSIONAL BUDGET REQUEST
GENERAL SCIENCE AND RESEARCH
HIGH ENERGY PHYSICS
VOLUME 4

TABLE OF CONTENTS

Physics Research 35
Facility Operations 38
High Energy Technology 48

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
HIGH ENERGY PHYSICS
GENERAL SCIENCE AND RESEARCH - OPERATING EXPENSES
GENERAL SCIENCE AND RESEARCH - PLANT & CAPITAL EQUIPMENT

(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
High Energy Physics (ER)				
Physics Research				
Operating Expenses...	$ 99,500	$107,494	$107,494	$111,300
Subtotal...........	99,500	107,494	107,494	111,300
Facility Operations				
Operating Expenses...	158,947	175,235	175,235	187,800
Capital Equipment....	51,500	58,700	58,700	63,100
Construction.........	81,000[a]	114,000	114,000	55,500
Subtotal...........	291,447	347,935	347,935	306,400
High Energy Technology				
Operating..............	82,000	90,200	90,200	92,400
Subtotal.............	82,000	90,200	90,200	92,400
Total				
Operating Expenses.....	340,447[b]	372,929	372,929	391,500
Capital Equipment......	51,500	58,700	58,700	63,100
Construction...........	81,000	114,000	114,000	55,500
Total High Energy Physics	$472,947	$545,629[c]/[d]	$545,629[c]/[d]	$510,100[e]

Staffing
FTP/Total FTEs (Reference General Science Program Direction Decision Unit)

Authorization: Section 209, P.L. 95-91.

---

[a] Reflects $5,000,000 transferred to Nuclear Physics.

[b] Does not include $2,053,000 transferred to the Energy Supply Research and Development Appropriation for use in accordance with the Small Business Innovation Development Act of 1982, P. L. 97-219.

[c] FY 1985 total reflects a reduction of $4,000,000 for Management Initiative Savings other than IG audits/deobligations contained in the FY 1985 President's Request.

[d] FY 1985 total reflects a reduction of $2,165,000 for ADP general reduction, and savings of $5,900 for Section 2901 of the Deficit Reduction Act of 1984 (P.L. 98-369).

[e] FY 1986 total reflects a reduction of $7,500,000 for FY 1986 Management Initiative Savings.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET

SUMMARY OF CHANGES
HIGH ENERGY PHYSICS
(In thousands of dollars)

1985 Appropriation enacted	$545,629
Built in increases and decreases	0
1986 Base	$545,629
Program increases and decreases:	
o Operating program at slightly reduced overall level of effort	+ 18,570
- Funding required to maintain constant level of program activity (based on analysis of cost inflation for high energy physics) (+20,510)	
- Pre-operating costs for Tevatron I and SLC (+10,000)	
- Average facility utilization level reduced to the 45-50 percent range (-7,075)	
- Physics research matched to the planned lower facility utilization level (-2,105)	
- Reduced level of advanced technology R&D activities (-2,760)	
o Capital equipment focusing on highest priority needs for the initial complement of Tevatron beams and detectors at Fermilab and for SLC detectors at SLAC, to permit effective utilization of the new capabilities made available by completion of Tevatron I, Tevatron II and SLC	+ 4,400
o Reduced overall level of line item construction activity	- 58,499
- Fermilab Central Computing Upgrade (+3,100)	
- Reduction resulting from completion of Tevatron II and declining level for Tevatron I & SLC (-62,299)	
- AIP and GPP at about FY 1985 level of effort (+700)	
1986 budget request	$510,100

High Energy Physics

The High Energy Physics program supports basic research which seeks to discover the fundamental constituents of matter and to understand the laws of nature that govern the fundamental behavior of matter and energy. Discoveries and new knowledge resulting from these activities in the past have laid the foundation for much of the highly technological world in which we live today. During this century, scientific investigation has advanced to studies of ever more fundamental constituents of matter, with the frontier moving from research on molecules to atoms, to nuclei; to the constituents of nuclei (protons and neutrons), and recently to even more elemental subnuclear constituents called quarks and gluons.

The Department of Energy provides over 90% of the Federal support for this most basic scientific endeavor, and serves as the Executive Agent for the national program. The Department has responsibility for planning for the national program, with the goals of achieving a forefront and productive national program and maintaining a competitive world leadership position for the United States.

The framework for understanding all natural phenomena has rested on the belief that they can be described in terms of four fundamental forces and a small set of basic constituents of all matter. The "electromagnetic" force describes how atoms and molecules are formed and is the cornerstone to understanding the periodic table of elements, chemistry, electronic communication and biological processes. The "weak nuclear" force describes processes such as the radioactive decay of unstable nuclei. The "strong nuclear" force describes how the sun and stars produce so much energy and, together with the weak nuclear force, describes the relative abundance of the chemical elements. The "gravitational" force describes falling objects, orbiting celestial bodies, the formation of black holes, and the large scale features of the universe.

Part of the recent great progress in science has been a reduction in the apparent number of basic forces through the conceptual unification of the weak nuclear and electromagnetic forces into a single force -- the electroweak force. Recent experimental evidence for the existence of the W and Z particles, the carriers of the weak force, together with earlier experimental discoveries of neutral weak currents and of particles with charmed quark constituents, confirm this conceptual unification. The electromagnetic and weak nuclear forces can now be viewed in a natural way as different aspects of a single electroweak force. The 1979 Nobel Prize in Physics was awarded to three theoretical high energy physicists (two from the U.S.) for their work toward this unification. The experiment at CERN which discovered the W and Z° and for which C. Rubbia and S. Van der Meer received the 1984 Nobel Prize included U.S. participation. Recent experimental evidence contains tantalizing hints that may signal a breakthrough to new physics beyond the electroweak unification, and which could shed light on the mechanism responsible for the unification.

There is increasing anticipation that the unification of the strong nuclear and electroweak forces into one "grand unified" force is possible, thereby further reducing the number of basic forces in nature to only two. The enormous energy scale at which this grand unification is expected to occur can be derived from basic theoretical techniques for whose development the 1982 Nobel prize in physics was awarded to a U.S. theoretical physicist. Theoretical predictions of grand unification give possible explanations for the observed excess of matter relative to antimatter in our universe. Other predictions of the grand unification models are that protons, which were previously thought to be absolutely stable, do eventually decay; and that neutrinos, which were previously thought to be massless, may in fact have a small mass. The 1980 Nobel Prize in Physics was awarded to two U.S. experimental high energy physicists for experimental research which indicated that certain elemental processes are not exactly reversible. This lack of exact reversibility, together with the mechanism involved in proton decay, could explain the observed excess of matter relative to antimatter in the universe. Special emphasis in the experimental program is focused on testing these predictions of the grand unified theories. The verification of these predictions by the experiments currently in progress would be a truly major scientific breakthrough. These new concepts also have profound implications for astrophysics, where they help provide an understanding of how the universe evolved from the proposed primordial big bang to its present state and whether the universe will expand forever or perhaps contract again in the distant future to another fireball. Exciting scenarios of the early expansion of the universe are being formulated which outline possible explanations to account for all the matter, energy and disorder in the universe. Recent discoveries and planned investigations in high energy physics provide crucial experimental input to these developments.

The goal is eventually to incorporate the gravitational force into a super-grand unification scheme, which would bring all of the basic forces into a single unified framework. Exactly what will follow from the various stages of unification cannot be predicted in any detail. However, one can certainly anticipate profound and practical impacts analogous to those which followed the unification of electricity and magnetism by Maxwell late in the 19th century, and the unification of matter and energy by Einstein early in this century.

Progress in high energy physics research is based on a complex and continuing interplay of advancements in experiment, theory and technology. Each is strongly dependent for its progress on the advancement of the others. High energy physics experiments expand the horizons of theoretical and technical knowledge, and the range of possible experiments is determined by technological as well as conceptual capabilities and limitations. Physicists frequently have to invent new and unique apparatus and novel techniques in order to carry out the experiments of greatest interest, thereby contributing directly and immediately to the technology resources of the country.

To probe deep into the depths of matter, into the domain of quarks, gluons, and other new particles, it is most effective to use intense beams of very energetic particles which are only available from high energy particle accelerators. By studying the results of the violent collisions of these accelerated particles with other particles in a dense fixed target or in another beam, information is acquired about the constituents of those particles, about the forces which act within and between them, and about the transformations between matter and energy. The high energy particle accelerator and colliding beam facilities to be operated by the Department in FY 1986 include: the 30 GeV (billion electron volt) proton synchrotron, the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL); the 1000 GeV Tevatron superconducting magnet proton synchrotron at Fermi National Accelerator Laboratory (Fermilab), and the 32 GeV linear electron accelerator at the Stanford Linear Accelerator Center (SLAC). SLAC also has two electron-positron colliding beam facilities for which the linear accelerator serves as an injector: the Stanford Positron Electron Asymmetric Ring (SPEAR) (4 GeV on 4 GeV) and the Positron-Electron Project (PEP) (15 GeV on 15 GeV). Each of these DOE accelerator centers provides a unique set of experimental research capabilities, complementary to the others. As an ensemble they provide the capabilities for a comprehensive forefront national research program in high energy physics.

A major part of the funding of the high energy physics program is required to meet the direct needs of the accelerator laboratories to develop, maintain and operate the major accelerator, colliding beam and detector facilities. The facilities at these laboratories provide the source of experimental data for accelerator-based high energy physics research, more than 75% of which is carried out by university-based scientists. In this sense, most of the funding provided to the accelerator laboratories can be considered as indirect support to the university research programs.

At Fermilab, the world's first superconducting high energy accelerator is in routine operation delivering beam to a number of fixed target experiments at 800 GeV. Extensions are being made under the Tevatron I and Tevatron II construction projects. The Tevatron I project, which provides the capability for operating the superconducting synchrotron as a 1000 GeV on 1000 GeV proton-antiproton colliding beam storage ring, is scheduled for completion late in FY 1986. A key element of Tevatron I, an intense source of antiprotons, is scheduled to begin first operating tests late in FY 1985. The project remains on schedule with first research utilization expected at the beginning of FY 1987. The Tevatron II project is scheduled for completion by the end of FY 1985 and will provide a number of new and upgraded secondary beam enclosures and experimental halls for fixed target research programs.

At SLAC, the principal emphasis in recent years has been the systematic study of electron-positron collisions at center of mass energies between 4 GeV and 30 GeV. An extension of this capability will be provided by the Stanford Linear Collider (SLC). This project has as a major goal the development and demonstration of the fundamental technical feasibility of using linear accelerators with precisely controlled, high intensity, micron-sized beam pulses to provide a reliable source of high luminosity electron-positron collisions. The successful demonstration of the SLC capabilities is a critical step toward future electron-positron colliders at energies far beyond those which would be affordable with circular colliders. SLC construction is planned on a three year schedule which will give an operational 50 GeV on 50 GeV electron-positron collider by early FY 1987, providing earliest access to the scientifically exciting physics made possible by the anticipated copious production of the Z^0 boson in high energy electron-positron collisions. Pre-operating systems tests of SLC are planned to begin in FY 1986.

At BNL, the research program will make use of the unique new capability for accelerating high energy polarized protons in the energy range up to 26 GeV. Also, new and upgraded secondary beam lines and detectors will be available for a new generation of rare K-decay experiments which will test more precisely important theoretical predictions.

The highest priority for new high energy physics facilities is a large accelerator collider. This new facility is a proton-proton collider with an energy of 20 TeV (trillion electron volts) per beam and high luminosity, up to $10^{33}\text{cm}^{-2}\text{sec}^{-1}$ which is called the Superconducting Super Collider (SSC). Recent rapid progress in particle physics understanding and in accelerator technology, including the great success of the CERN laboratory in its successful construction and operation of a proton-antiproton colliding beam capability and the subsequent discovery of the W and Z particles, has emphasized the importance of physics experiments in the mass range up to several TeV where new phenomena, including new forms of matter with unique properties, are expected. The 20 TeV beam energy will allow the SSC to do this physics. The SSC would have immense physics potential for truly major advances in understanding the fundamental nature of matter. It would operate in an energy domain where there are no existing or planned facilities anywhere in the world, and it would assure a world competitive U.S. high energy physics program from the mid-1990's into the next century. Such a project has been made possible by the recent outstanding successes resulting from the substantial U.S. investment in superconducting magnet technology, demonstrated most specifically by successful operation of the Tevatron superconducting magnet ring at Fermilab.

Preliminary accelerator R&D related to the SSC was initiated in FY 1984. This work included R&D on technical options (particularly with regard to superconducting magnets), cost reduction studies, and reference design studies to establish technical feasibility and develop credible preliminary cost and schedule estimates. Research and development activities underway in FY 1985 include further R&D on superconducting magnet designs to determine which would yield the best performance for the SSC at the lowest cost; initiation of studies to refine the definition of the scope of the SSC and to develop a cost-optimized design.

In FY 1986, SSC related research and development would continue with emphasis on advanced accelerator R&D to develop a cost/performance optimized design for the selected superconducting magnet type and to develop cost effective techniques for fabrication of superconducting magnets. Advanced detector R&D is also important to develop new concepts for the detectors required to effectively utilize the high luminosity and energy of SSC.

In addition to research carried out using high energy accelerators in the U.S., the Department's high energy physics program supports other experiments which use the capabilities of unique foreign accelerators and also other experiments which do not require beams from particle accelerators. The research carried out at facilities overseas takes advantage of unique research opportunities offered by foreign accelerator facilities which have capabilities not available in the U.S. The research using particles from non-accelerator sources includes studies of very rare processes such as the predicted decay of the proton, and searches for neutrino mass and isolated magnetic monopoles. The proton decay experiments employ large detector systems located in deep underground locations to provide an environment with low background radiation.

The FY 1986 budget request addresses the funding requirements to permit utilization of facilities in the 45-50 percent range; to meet the highest priority needs for the initial complement of detectors for Tevatron and SLC; to complete the Tevatron I and SLC construction projects; to upgrade the central computing capability at Fermilab; and to continue advanced technology R&D.

The FY 1986 request for operating expenses is $391,500,000. A major feature of the program in FY 1986 will be the operation of the Tevatron superconducting synchrotron at Fermilab for fixed-target experiments in the 800-1000 GeV energy range and pre-operating tests of the proton-antiproton colliding beam capability provided by Tevatron I. The program will also include operation and research utilization of the AGS with its new unique high energy polarized proton beam, operation of PEP and pre-operating systems tests of the SLC. The overall utilization level of the accelerator facilities will be in the 45-50 percent range, compared to the FY 1985 level of about 50 percent. The request provides support for continuing participation by university based groups in experimental research including accelerator user group efforts and non-accelerator experiments, and for theoretical research efforts. The FY 1986 program also includes funding for continuation of advanced technology R&D at about the 1985 level of effort.

The FY 1986 capital equipment request of $63,100,000 provides an increase above the FY 1985 level adequate to meet the highest priority needs associated with the initial complement of detectors and secondary beams required to implement the research programs using the major new capabilities being provided by the Tevatron projects at Fermilab and by the SLC electron-positron collider at SLAC. The initial complement needs for Tevatron and SLC account for $30,600,000 of the request. The equipment request for FY 1986 is essential for effective utilization of the new U.S. High Energy Physics facilities being completed in FY 1985 and FY 1986 at Fermilab and SLAC.

The request for construction funds is $55,500,000. The major features are the completion of construction of the SLC project at SLAC ($22,900,000); completion of the Tevatron I project at Fermilab ($8,600,000); and work on upgrading of the central computing capability at Fermilab ($3,100,000) which is required for the analysis of the large volume of new physics data coming from the Tevatron program. Funds are also requested for Accelerator Improvement Projects (AIP) ($10,500,000), and for General Plant Projects ($10,400,000).

The accelerator improvement projects are essential on an annual level of effort basis for maintaining the reliability and efficiency, as well as the scientific effectiveness of the existing accelerator facilities. GPP projects are required to keep the general plant of the laboratories, including buildings, utilities and roads, in viable operating condition. The High Energy Physics program has the responsibility to provide for the full GPP needs of the multi-program laboratory at Brookhaven.

The High Energy Physics program is described in terms of three sub-programs: Physics Research, Facility Operations and High Energy Technology. Although these three functions within the program are discussed as separate sub-programs, they are not independent. Each is coupled to the other two and cannot exist separately. The close interaction and dynamic nature of these three subprograms may require that some adjustments among the subprograms be permitted during the year, in order to ensure the most effective program and the best use of overall program funds.

The High Energy Physics program supports numerous university research contracts in which there is substantial cost sharing by the universities. The universities' contributions are provided in a number of ways, such as, salaries to investigators, provision of laboratory space and shop facilities, computing time and/or equipment, etc. The High Energy Physics program encourages such cost sharing policies to achieve maximum utilization of available Federal funds. In addition, there is cost sharing in a number of experiments by foreign participants, including substantial contributions to major detectors, such as the Japanese and Italian support of the Collider Detector at Fermilab (CDF).

Physics Research	FY 1984	FY 1985	FY 1986 Request
Operating Expenses........................	$ 99,500	$107,494	$111,300

The Physics Research subprogram includes the direct support of university- and laboratory-based research groups for the planning, preparation and execution of experiments, and for the measurement, analysis, interpretation and dissemination of experimental results. It also supports the research of university- and laboratory-based theoretical physicists in both phenomenological and formal areas of theoretical study.

Experiments in high energy physics generally require the use of large particle accelerators together with complex detection apparatus to study the products of collisions of high energy particles. The DOE-supported accelerators and experimental facilities are located at three central laboratories where they are accessible to qualified scientists on the basis of the scientific merit and promise of their proposed research. More than 75 percent of the research done with these central accelerators is performed in a user mode by university-based physicists. Because of the size and complexity of a typical high energy physics experiment, users from a number of institutions frequently collaborate on a given experiment. The resultant research teams typically include a mix of physicists, engineers, technicians, and graduate students. After a research proposal to the laboratory is accepted, the research teams assist in the design and fabrication of detectors and provide manpower for the experiment during the data-taking phase at the laboratory. There is usually significant interaction and assistance from laboratory staff and the use of laboratory support facilities for each experiment. The entire process, from conception of the experiment to publication of results, usually takes three to five years if no major new detector is involved; if major detector design and fabrication is involved the duration can be several years longer. U.S. user group participation in experiments utilizing unique capabilities and opportunities at foreign laboratories such as DESY (West Germany), CERN (Western Europe), and KEK (Japan) is also supported.

Studies of some of the important fundamental problems in high energy physics are being carried out in experiments which do not involve the use of high energy accelerators. While experiments to search for proton decay currently represent the largest of the non-accelerator experimental efforts, there are other experiments, both proposed and in operation, including: searches for free quarks, magnetic monopoles, and neutrino mass; and measurement of neutrino-less double beta decay.

Theoretical research provides a framework for understanding the results of experimentation and provides suggestions for new measurements important for advancement of understanding. Experiments test existing theory, and often provide the basis for extensions, revisions and modification of the theoretical framework and understanding. Because of this strong interplay between, and interdependence of, experimental and theoretical research, experimental and theoretical research groups often work closely together. High energy theoretical research presently has a strong focus on developing a unified description of the forces in nature through generalized gauge-invariant field theories. An increasingly successful trend in theoretical research is the use and development of large-scale computing facilities to explore numerical solutions of candidate theories which are not amenable to analytic methods, along with the development of more powerful numerical and analytical techniques. The Physics Research Subprogram also includes the Outstanding Junior Investigator program which provides research support for outstanding untenured high energy physicists who might otherwise have to leave the field due to lack of availability of permanent positions. This small program is very important for encouraging some of the best young scientists to enter and to remain in this research, and thus bears importantly on the long range vitality of the field.

The FY 1986 budget request of $111,300,000 for Physics Research will support a somewhat reduced level of effort relative to FY 1985. The funds requested are necessary to maintain the capability of the university and laboratory research groups to participate effectively in today's more complex experiments, particularly those using the new capabilities at Fermilab and SLAC; to provide a decreased level of effort matched with the planned level of facility utilization, and to allow continuation of the important theoretical research and non-accelerator high energy physics research programs.

Distribution by Facility

	FY 1984	FY 1985	FY 1986 Request
Fermi National Accelerator Laboratory (Fermilab)	$ 9,075	$ 9,600	$ 9,800
Brookhaven National Laboratory (BNL)............	6,900	7,100	7,300
Stanford Linear Accelerator Center (SLAC).......	10,506	11,100	11,300
Argonne National Laboratory (ANL)...............	4,500	4,800	5,000
Lawrence Berkeley Laboratory (LBL)..............	8,026	8,400	8,700
Universities and other agency Laboratories......	60,493	66,494	69,200
Total Physics Research.......................	$ 99,500	$107,494	$111,300

Fermi National Accelerator Laboratory

In FY 1986 $9,800,000 is requested for the support of the Fermilab in-house research effort, compared to $9,600,000 in FY 1985. This level will permit continued physics research activity by Fermilab scientists. Most of the research of the Fermilab scientists is done in collaboration with university-based groups from across the country; in this mode the Fermilab staff participate in forefront research while simultaneously providing a crucial support and liaison function for the many university users of Fermilab. One major focus of their research efforts will be the new physics opportunities becoming available with completion of the Tevatron II construction and preparation for Tevatron I experiments.

The major lines of research to be pursued by Fermilab scientists in FY 1986 will be searches for new particles, studies of nucleon structure and constituents, and exploration of the electroweak force through neutrino interactions. The 800-1000 GeV capability of the superconducting synchrotron, in conjunction with upgraded and new experimental facilities provided by the Tevatron II project, will offer many highly promising new and unique opportunities for research advances. Major experiments will study the properties of jets of particles produced with high transverse momentum; the dimuon spectrum resulting from energetic proton collisions with a fixed target; the characteristics of interactions of neutrinos at the higher energy now available; the substructure of the nucleons using the superconducting "Chicago Cyclotron" magnetic spectrometer; and the creation of charmed and heavier quark states by photons in photoproduction experiments at new higher energies. The requested funds also include support for the Fermilab theoretical physics research program, including a small effort which explores the interface region between astrophysics and high energy physics.

Brookhaven National Laboratory

In FY 1986 $7,300,000 is required for the BNL in-house research program, compared to $7,100,000 in FY 1985. The research capabilities at the AGS are unique, since no other accelerator covers this range of beam energies or can provide beams of high energy polarized protons. Major research thrusts during FY 1986 will be on the study of the interactions of polarized beams on both unpolarized and polarized targets utilizing the new unique high energy polarized beam capability at the AGS, on a search for neutrino oscillations, and on a variety of innovative studies of rare K decays. Most of this work will be performed in collaboration with university groups. A complementary program of theoretical analyses of experimental results and more formal theoretical studies will also be pursued.

Stanford Linear Accelerator Center

In FY 1986 $11,300,000 is requested for support of SLAC physics research groups, compared to $11,100,000 in FY 1985. In FY 1986, PEP is expected to operate at a record high luminosity which will provide excellent opportunities for new discoveries. New particle searches will be performed with better sensitivity, and higher precision experiments including measurements of electroweak asymmetries and particle lifetimes will be emphasized. The SPEAR detector (Mark III) will continue taking data, concentrating on states in the Psi region to obtain a better understanding of charmed quark matter. Final preparations will be made for first experiments with the upgraded Mark II detector at SLC early in FY 1987. The theoretical program at SLAC includes phenomenological studies, as well as studies of fundamental issues concerning properties of the basic forces, the constituents of matter and the unification of forces.

Argonne National Laboratory

In FY 1986 $5,000,000 is requested for the ANL physics research program, compared to $4,800,000 in FY 1985. ANL scientists are primary participants in the operation of the High Resolution Spectrometer (HRS) at PEP, in the data-taking and analysis phases of experiments with HRS, and in the upgrading of this facility. They are also involved in preparations for experiments to study 1000 GeV on 1000 GeV proton-antiproton collisions with the CDF detector at Fermilab, and are major participants in the Soudan II nucleon decay experiment. The ANL physicists collaborate closely in these activities with university research groups and, together with the unique ANL laboratory capabilities, provide an important technical service base for these groups. The high energy theoretical physics group at ANL focuses on the study and formulation of phenomenological models for strong interactions.

Lawrence Berkeley laboratory

The request provides $8,700,000 in FY 1986 for the LBL research program compared to $8,400,000 in FY 1985 to maintain an approximately constant overall level of activity. These funds are required for participation of the LBL research groups in experiments at SLAC/PEP, Fermilab and BNL. LBL will continue to play a major role in experiments at PEP including use of the Time Projection Chamber and analysis of data from the Mark II Magnetic Detector. LBL scientists are also participating in a neutrino oscillation search experiment at BNL. An important part of the LBL program is the Particle Data Center, which is the only such capability in the U.S. and which provides a valuable service function for the U.S. and worldwide high energy physics communities. Modest support for high energy astrophysics experiments in 3 degree Kelvin background radiation, supernova detection and observation, and studies of compact stellar objects is expected to continue. These experiments provide important data on elementary processes and complement other high energy physics experiments. Theoretical physics at LBL will continue to emphasize the investigation of the basic particle interaction, the fundamental structure of matter, and topics in advanced accelerator physics.

Universities and other Agency Laboratories

The Physics Research request for FY 1986 provides $69,200,000 compared to $66,494,000 in FY 1985, for the support of many university-based experimental and theoretical research groups and for high energy physics research programs at the Ames Laboratory, Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL) and Pacific Northwest Laboratories (PNL). This amount is required to permit these research groups to participate effectively as users at U.S. accelerator laboratories and unique foreign facilities; to perform new forefront non-accelerator experiments; to conceive and test innovative ideas for the next generations of experiments; and to make available opportunities for selected outstanding junior investigators to do independent research.

The Department supports approximately 115 experimental and 65 theoretical high energy physics research groups at 90 universities across the nation, as well as the research efforts at Ames, LANL, ORNL and PNL. DOE University-based high energy experimental groups are engaged in over 200 forefront experiments in various stages of progress, collecting data from the U.S. accelerators at BNL, Cornell, Fermilab, or SLAC, and also from European accelerators at the European Center for Nuclear Research (CERN) and the Deutsches Elektronen-Synchrotron (DESY), from the Japanese facility at KEK, and from non-accelerator settings (e.g., deep mines for proton decay). Such well-conceived and carefully executed experiments provide the basis for progress in the field. This work has included participation in the development of powerful methods for calculating lattice gauge formulations of quantum chromodynamics, for predicting the results of electroweak interactions and for developing the specifications for new large computer architectures.

Facility Operations	FY 1984	FY 1985	FY 1986 Request
Operating expenses	$158,947	$175,235	$187,800
Capital equipment	51,500	58,700	63,100
Construction	81,000	114,000	55,500
Total facility operations	$291,447	$347,935	$306,400

Facility Operations supports all of the many activities required to operate, maintain, equip, and construct the high energy accelerators, colliding beam facilities, experimental areas, secondary beams, large multi-user detector facilities, and to support facilities essential to the pursuit of experimental high energy physics research.

	FY 1984	FY 1985	FY 1986 Request
Operating Expenses	$158,947	$175,235	$187,800

The operating expenses portion of Facility Operations provides funding for the accelerator and experimental facility operating crews and support personnel, the electric power, and the expendable materials and supplies required for these activities, which are concentrated at the three DOE high energy accelerator centers located at BNL, Fermilab and SLAC. These accelerator facilities provide the beam time for the research work of most of the high energy physics experimental research groups in the U.S. including those who receive their direct research support from the National Science Foundation (NSF) and those foreign groups collaborating on experiments at U.S. facilities. The accelerator and colliding beam facilities required for research in high energy physics are large, complex and expensive; hence, they are few in number and are operated as national facilities at national centers and made available to the most qualified physicists whose research proposals are judged to have the highest scientific promise and merit.

The complementary capabilities at the three accelerator centers provide the essential variety in types of particle beams, particle energy and beam intensity for a productive U.S. high energy physics program. At Fermilab, the superconducting magnet proton synchrotron provides intense beams of protons, with energies up to about 1000 GeV, which produce various types of secondary particle beams with the high energies and high intensities needed for forefront fixed target experiments. In FY 1986, the 1000 GeV on 1000 GeV proton-antiproton colliding beam facility with Tevatron I will undergo pre-operating tests. At BNL, the AGS provides protons with energies up to 30 GeV in the primary beam, high energy polarized proton beams up to about 26 GeV, and unique secondary particle beams and neutrino beams for use in fixed target experiments. At SLAC, the two-mile linear accelerator delivers electrons up to 32 GeV, positrons up to 21 GeV and secondary particle beams for use in fixed target experiments. Improvements to the linac will raise its energy for both electrons and positrons to 50 GeV by the end of FY 1986. Also at SLAC, the PEP colliding beam facility stores electrons and positrons for collisions at 15 GeV on 15 GeV with high luminosities and the SPEAR facility provides similar capabilities for collision energies up to 4 GeV on 4 GeV. Late in FY 1986 the 50 GeV on 50 GeV positron-electron collider SLC will begin pre-operating tests in preparation for research early in FY 1987.

The funding request in FY 1986 will provide an average utilization level in the 45-50 percent range, and will provide for operation of a more fully developed 1000 GeV fixed target program at Fermilab, pre-operating tests of the new 1000 GeV on 1000 GeV colliding beam facility provided by with Tevatron I, and pre-operating tests of the SLC.

Operating Expenses
Distribution by Facility

	FY 1984	FY 1985	FY 1986 Request
Fermilab..................................	$ 75,547	$ 83,520	$ 90,700
BNL..	33,800	36,265	37,400
SLAC/PEP...................................	48,400	50,850	54,700
LBL..	700	700	700
Other......................................	500	3,900	4,300
Total Facility Operations.........	$158,947	$175,235	$187,800

Fermi National Accelerator Laboratory

The FY 1986 request for Facility Operations at Fermilab is $90,700,000 compared to $83,520,000 in FY 1985. The superconducting magnet accelerator will be operated for seven months in FY 1986, the same as in FY 1985. Operation of the entire expanded sequence of accelerators at Fermilab (Cockroft-Walton preaccelerator, linac, booster, main ring, superconducting Tevatron ring and antiproton source storage rings) will require $53,400,000. The FY 1986 program is expected to include 5 months of operation in the fixed target research mode at energies of 800-1000 GeV, one month for commissioning of the colliding beam capability and one month for start-up activities. Initiation of the colliding beam studies requires operation of the antiproton source, which includes a complex target facility and two new storage ring accelerators. During the extended shutdown of the main ring and Tevatron for construction activities, the antiproton source commissioning will be done using a low intensity beam of protons from the Fermilab booster accelerator. This will necessitate operation of the preaccelerator, linac, booster and antiproton source storage rings during most of FY 1986. Operation of the laboratory's extensive complex of secondary beams, fixed target detectors and colliding beam detectors will require $37,300,000. During the five months of operation for the fixed target program, about ten secondary beam lines will provide a variety of intense high energy particle beams for research use, and about 12 different experiments are expected to take data during FY 1986. The colliding beams commissioning program will provide the first test data for the massive new Collider Detector at Fermilab (CDF), and simultaneously for 3 other small colliding beams experiments which will be housed within the existing Fermilab main ring tunnel. The Fermilab research program in FY 1986 will exploit the availability of particle beams of higher energies and, in most cases, higher intensities than are available anywhere else in the world. It is a world unique and truly forefront program which has priority within the national high energy physics program.

Brookhaven National Laboratory

In FY 1986 $37,400,000 is requested for operation of the AGS and associated experimental facilities compared to $36,265,000 in FY 1985. Of this amount, $18,800,000 is needed for accelerator operations and $18,600,000 is needed for experimental facility operations. This will support about a 30-week level of machine operation, about the same as in FY 1985. The FY 1986 operating program is expected to include 12 weeks of slow extracted beam operation, 9 weeks of fast extracted beam operation for neutrino experiments, and 9 weeks of polarized proton beam operation.

Stanford Linear Accelerator Center

$54,700,000 is requested in FY 1986 for facility operations at SLAC compared to $50,850,000 in FY 1985. Of the request, $28,600,000 is for the operation of the linear accelerator, SPEAR and PEP and for pre-operations of SLC, and $26,100,000 is for the operation of the experimental areas, detector facilities and the central computer facility. This should make it possible to operate the linear accelerator for about 26 weeks, somewhat less than in FY 1985. This reduction is due in part to the increased power costs at SLAC. The delivery rate of electron pulses, which primarily affects the fixed target research program, would be about 16% of maximum capability. (The facility operating levels will be considerably lower than projected at this funding level if SLAC loses its withdrawable electric power allocation from WAPA.) Operation of PEP is expected to continue at a high level of productivity with higher luminosity and an improved set of major detectors. SPEAR storage ring operations will continue to be half-time for high energy physics research, and half-time for the Stanford Synchrotron Radiation Laboratory which is supported by the Basic Energy Sciences Program. The high energy physics portion of SPEAR operation will focus on the use of the improved Mark III general purpose magnetic detector for studying detailed properties of the charmed particles. The FY 1986 SLAC program will also include pre-operating tests and checkout of the SLC.

Fermi National Accelerator Laboratory

The FY 1986 request for Facility Operations at Fermilab is $90,700,000 compared to $83,520,000 in FY 1985. The superconducting magnet accelerator will be operated for seven months in FY 1986, the same as in FY 1985. Operation of the entire expanded sequence of accelerators at Fermilab (Cockroft-Walton preaccelerator, linac, booster, main ring, superconducting Tevatron ring and antiproton source storage rings) will require $53,400,000. The FY 1986 program is expected to include 5 months of operation in the fixed target research mode at energies of 800-1000 GeV, one month for commissioning of the colliding beam capability and one month for start-up activities. Initiation of the colliding beam studies requires operation of the antiproton source, which includes a complex target facility and two new storage ring accelerators. During the extended shutdown of the main ring and Tevatron for construction activities, the antiproton source commissioning will be done using a low intensity beam of protons from the Fermilab booster accelerator. This will necessitate operation of the preaccelerator, linac, booster and antiproton source storage rings during most of FY 1986. Operation of the laboratory's extensive complex of secondary beams, fixed target detectors and colliding beam detectors will require $37,300,000. During the five months of operation for the fixed target program, about ten secondary beam lines will provide a variety of intense high energy particle beams for research use, and about 12 different experiments are expected to take data during FY 1986. The colliding beams commissioning program will provide the first test data for the massive new Collider Detector at Fermilab (CDF), and simultaneously for 3 other small colliding beams experiments which will be housed within the existing Fermilab main ring tunnel. The Fermilab research program in FY 1986 will exploit the availability of particle beams of higher energies and, in most cases, higher intensities than are available anywhere else in the world. It is a world unique and truly forefront program which has priority within the national high energy physics program.

Brookhaven National Laboratory

In FY 1986 $37,400,000 is requested for operation of the AGS and associated experimental facilities compared to $36,265,000 in FY 1985. Of this amount, $18,800,000 is needed for accelerator operations and $18,600,000 is needed for experimental facility operations. This will support about a 30-week level of machine operation, about the same as in FY 1985. The FY 1986 operating program is expected to include 12 weeks of slow extracted beam operation, 9 weeks of fast extracted beam operation for neutrino experiments, and 9 weeks of polarized proton beam operation.

Stanford Linear Accelerator Center

$54,700,000 is requested in FY 1986 for facility operations at SLAC compared to $50,850,000 in FY 1985. Of the request, $28,600,000 is for the operation of the linear accelerator, SPEAR and PEP and for pre-operations of SLC, and $26,100,000 is for the operation of the experimental areas, detector facilities and the central computer facility. This should make it possible to operate the linear accelerator for about 26 weeks, somewhat less than in FY 1985. This reduction is due in part to the increased power costs at SLAC. The delivery rate of electron pulses, which primarily affects the fixed target research program, would be about 16% of maximum capability. (The facility operating levels will be considerably lower than projected at this funding level if SLAC loses its withdrawable electric power allocation from WAPA.) Operation of PEP is expected to continue at a high level of productivity with higher luminosity and an improved set of major detectors. SPEAR storage ring operations will continue to be half-time for high energy physics research, and half-time for the Stanford Synchrotron Radiation Laboratory which is supported by the Basic Energy Sciences Program. The high energy physics portion of SPEAR operation will focus on the use of the improved Mark III general purpose magnetic detector for studying detailed properties of the charmed particles. The FY 1986 SLAC program will also include pre-operating tests and checkout of the SLC.

Lawrence Berkeley Laboratory

The request provides $700,000 for support of LBL's participation in the operation of the Time Projection Chamber (TPC) detector facility at PEP. LBL provides engineers, computer scientists, technicians, and physicists who are responsible for reliable operation of the TPC.

Other

In FY 1986 $4,300,000 is requested for special process spares, common use stores and other specialized activities to meet requirements for effective operation of the accelerator laboratories. An adequate complement of spares and specialized replacement parts is essential to avoid unnecessary disruptions to the operating schedule in the event of component failures. These very complex and advanced technology facilities require many components that are not off-the-shelf items but must be custom made in advance if they are to be readily available when a replacement part is needed.

	FY 1984	FY 1985	FY 1986 Request
Capital Equipment......................	$51,500	$58,700	$63,100

Capital Equipment funding is required to provide the secondary beam line components, particle detection apparatus, portable shielding, and data analysis systems essential to do high quality, forefront high energy physics experiments. It is also required for replacement of accelerator and detector facility components that have worn out or become obsolete. A proper complement of detectors and secondary beams is absolutely essential for effective utilization and operation of the major high energy physics accelerator and colliding beam facilities. A large part of the FY 1986 request is required to provide the initial complement of detectors to utilize the new and unique research capabilities of Tevatron I, Tevatron II and SLC.

Timely introduction of new beam and detector capabilities and the regular upgrading and modification of existing capabilities is essential. The large scale of the high energy physics research systems is illustrated by the following examples: a typical secondary beam line can range from several hundred feet to a mile or more in length, and requires many beam transport, beam shaping and control elements; the portable shielding required around detectors and targets can involve arrays of hundreds of shielding blocks weighing as much as 10 tons each; the analysis magnets incorporated in detection systems weigh many tons; large calorimeters of 100 tons or more are not uncommon; and electronics systems with hundreds of thousands of data channels are typically required for major detectors. A time span of as much as five years is often involved from design, through fabrication, to installation, checkout and operation of these large systems. Examples of specific items of equipment needed include beam transport magnets, precision large volume analysis magnets for detector systems, precision regulated power supplies, particle beam diagnostic and control systems, electronic and optical detectors with improved spatial and time resolution, high speed and large volume data processing systems, special cryogenic components for liquid hydrogen targets and superconducting devices, and a host of specialized electronics and laboratory support equipment items.

In FY 1986, $63,100,000 is requested to meet the most urgent capital equipment needs of the program, with particular emphasis on the initial complement of major detectors required for adequate utilization of the new research capabilities coming into operation at Fermilab and SLAC. The initial complement needs account for $30,600,000 of the request. At Fermilab the needs are related primarily to fabrication of detectors for proton-antiproton colliding beam experiments with Tevatron I and to completion of secondary beams and detectors required for experiments using the fixed target capability provided by the Tevatron II project. At SLAC major new needs are related to work on detectors for SLC and to upgrading of existing PEP detectors for second generation experiments. There are also needs for university users, for non-accelerator experiments, and for U.S. participation in international collaborative experiments at unique foreign facilities.

High Energy Physics
Summary of Capital Equipment by Laboratory

	FY 1984	FY 1985	FY 1986 Request
Fermilab	$26,450	$28,000	$29,000
BNL	3,400	4,000	4,300
SLAC	6,184	9,500	11,300
LBL	3,127	1,300	1,500
ANL	765	500	500
Other DOE laboratories and universities	8,074	11,500	12,600
General Purpose Equipment (BNL)	3,500	3,900	3,900
Total capital equipment	$51,500	$58,700	$63,100

Fermi National Accelerator Laboratory

In FY 1986, $29,000,000 is requested for capital equipment for the Fermilab program. Initial complement needs associated with Tevatron I and Tevatron II account for $23,200,000 of the request. A major need ($10,200,000) is for the secondary beam lines and initial complement of detectors which are essential for adequate utilization of the new Fermilab fixed target research capability at the 1000 GeV level made possible by Tevatron II construction. Another major need ($13,000,000) is for work on the two large colliding beam detectors necessary for proton-antiproton colliding beam experiments at the B-Zero and D-Zero intersection regions of Tevatron I ($8,000,000 and $5,000,000, respectively).

Summary of Capital Equipment Request for Fermilab

	FY 1986 Request
Initial Complement of Detectors for Effective Utilization of Tevatron I and Tevatron II	$ 23,200
Detectors for 1000 GeV fixed target experiment	(5,200)
Secondary beam line components and shielding	(5,000)
1000 GeV on 1000 GeV colliding beam detectors	(13,000)
Base Program Needs	$ 5,800
Accelerator related equipment items	(1,900)
Support equipment for experimental program	(1,700)
General computing equipment	(1,300)
Technical support and site operations equipment	(900)
Total	$ 29,000

In the fixed target program several new experimental detectors need to be completed and brought into operation during FY 1986 in order to exploit the 1000 GeV capabilities resulting from completion of the Tevatron II construction project. The requested $5,200,000 for fixed target detectors includes $400,000 for approved experiments in the Neutrino Area, $2,000,000 for experiments in the Proton Area, and $2,800,000 for experiments in the Meson Area.

Several new secondary beam line facilities need to be equipped with technical components in FY 1986. The major requirements for secondary beam transport lines include magnets, control systems and instrumentation, cryogenics for the superconducting magnets and shielding. A total of $5,000,000 is requested for such secondary beam equipment. The major efforts on new beams in FY 1986 will include work on the muon beam ($900,000), wide band photon beam ($800,000), polarized proton beam ($1,100,000), the new higher energy proton and pion beam in the Meson Area ($1,500,000). The remaining $700,000 is for a number of smaller upgrades and modifications.

Two major colliding beam detectors are being fabricated at Fermilab to conduct research at the unprecedented reaction energies scheduled to become available for the first time late in 1986, when the Tevatron I project is completed and becomes operational. The Collider Detector at Fermilab (CDF) is being assembled at the B-Zero interaction region of the Tevatron. It is essential that CDF be ready for initial research operation during the latter half of 1986. It will provide our first glimpse of new physics at reaction energies in the 2000 GeV range, and will be the only general purpose large solid angle detector available when Tevatron I research operation begins early in FY 1987. The $8,000,000 requested in FY 1986 will complete the funding for CDF. Fabrication of the second colliding beam detector, to be installed at the D-Zero interaction region of the Tevatron, was initiated in FY 1985. The $5,000,000 requested in FY 1986 for the D-Zero colliding beam detector is required to maintain a schedule that makes it possible for the D-Zero detector to be completed in FY 1989.

The numerous and technologically advanced accelerator and cryogenic systems at Fermilab require replacement items of capital equipment in order to maintain good operating condition and for the replacement of worn out and obsolete units. Items needed include components of the power, vacuum, RF, controls and cryogenic systems. Some electronics and stochastic cooling equipment needed for the R&D program supporting accelerator operations are included in this category. A network of small emulators and microprocessors, to provide more efficient access by users to the Fermilab central computing complex, is also required in FY 1986. Small additions to the central computing peripheral equipment are included as well.

A variety of standardized electronics modules and other items of support equipment are required by the experimental program at Fermilab. Technical support and site operations equipment needed in FY 1986 includes machine tools, vehicle replacements, general office equipment and items to facilitate vehicle and plant maintenance efforts and warehouse operations.

Brookhaven National Laboratory

The FY 1986 request of $4,300,000 for BNL includes $3,800,000 for needs of the ongoing AGS physics program. This includes $1,800,000 for detection equipment for the BNL physics research groups, a major share of which will be utilized for the rare kaon decay experiments; $900,000 for components for secondary beam line modifications; $600,000 for controls and instrumentation in various parts of the AGS complex; and $500,000 for the instrumentation pool which provides modules of standardized electronic apparatus which are available to all AGS users on the basis of need.

The remaining $500,000 is for equipment needed to support the Accelerator and Facility R&D programs. This includes $225,000 for magnet test instrumentation, $175,000 for cryogenic equipment, and $100,000 for minicomputers for monitoring and data collection applications.

Stanford Linear Accelerator Center

The request of $11,300,000 in FY 1986 is required to meet equipment needs related to the SLAC linear accelerator, the SPEAR and PEP storage rings, the associated experimental detection facilities, upgrading of the Mark II detector and work on a new detector for use at SLC, and the SLAC advanced accelerator R&D programs.

Of the $3,900,000 requested for non-SLC related activities, major activities include upgrading of two of the major detectors at PEP (TPC and HRS) and provision of the micro-beta modification of the PEP lattice for increased luminosity. The $500,000 required in support of SLAC's accelerator research and development effort includes equipment needs for improvements to the linac beam, for work on surface physics and superconductivity and for the research and development on advanced linear collider concepts. There are also needs for $500,000 for improvements to the central computing system and its associated SLAC based network, and $500,000 for general laboratory support equipment.

Of the $7,400,000 requested for SLC detectors, $2,100,000 is required to complete the upgrade of the Mark II detector to operate effectively at the SLC energies. Mark II should be in operation at SLC turn-on and thus provide a quantitative test of the success of the linear collider concept in providing high luminosity collisions at 100 GeV. It will explore physics in the new energy region, concentrating on production of the Z°. The remaining $5,300,000 is provided for progress on a new SLC detector designed and scoped specifically for experiments at 50 GeV on 50 GeV. This detector will include calorimetry and particle identification over a large solid angle for more detailed studies of Z° physics. The FY 1986 request is needed to maintain a schedule that makes it possible for this state-of-the-art detector to be completed in FY 1989.

Lawrence Berkeley Laboratories

A total of $1,500,000 is requested for capital equipment needs at LBL. The physics research program requires $1,000,000 for the support of ongoing experiments at PEP, and BNL (the muon-neutrino mass experiment), and the double beta-decay experiment. The advanced accelerator R&D effort requires $500,000 for equipment related to LBL's effort on antiproton cooling on very high field superconducting accelerator magnets and for special purpose computing devices used in performing orbit tracking calculations for advanced accelerator design.

Argonne National Laboratory

A total of $500,000 is requested for ANL capital equipment needs in FY 1986. This equipment will support ANL's participation in a variety of experiments including the polarized proton beam experiments at Fermilab and the Soudan II neutrino oscillation experiment.

Other

The $11,600,000 requested for university programs is required for experimental detection and data analysis equipment. These funds support primarily the major apparatus needs of the experimental research programs of the university users for experiments at U.S. and foreign national accelerator laboratories, and for non-accelerator experiments such as studies of nucleon decay, neutrino oscillations, double beta decay, and magnetic monopoles. There are major equipment needs for user groups participating in experiments using the 1000 GeV Tevatron capability at Fermilab; for utilization of the high intensity capability of the AGS at BNL for neutrino oscillation, rare kaon decay and polarized beam experiments; for electron-positron colliding beam experiments at SLAC: for participation of U.S. universities in major electron-positron colliding beam experiments presently in the preparation stage at the LEP facility at CERN; for participation of U.S. universities in the TRISTAN colliding beam experimental program at KEK; and with non-accelerator experiments such as the proton decay searches which are operated in deep mines. On-line computer equipment, interfacing components and peripherals, which are an integral part of experimental detector systems, and small computer systems used in scanning, measuring, and data analysis, are also provided to university experimental groups. In addition, theoretical groups based at universities have a requirement for special computing capability for some types of research such as lattice gauge calculations.

$500,000 is requested for capital equipment items required in support of SSC R&D efforts. This would include magnet testing, cryogenics and vacuum equipment; computing devices for beam dynamics studies and control system development; and laboratory electronics instrumentation.

The FY 1986 request also includes $500,000 for Ames Laboratory for detector components used in experiments at Fermilab and at CERN.

General Purpose Equipment (BNL)

The High Energy Physics program provides funding for all general purpose equipment requirements at BNL. In FY 1986 $3,900,000 is requested for this multipurpose equipment, which is essential to the proper day-to-day operations at the Laboratory. Included are all the needs of the Laboratory's service and support divisions, central scientific computing facility and central shops, as well as equipment required to respond to health, safety, security and environmental needs. It is important that obsolete and worn-out equipment be replaced in order to promote efficient, safe laboratory operations, to increase productivity, and to avoid high maintenance costs.

	FY 1984	FY 1985	FY 1986 Request
Construction............................	$81,000	$114,000	$55,500

A total of $55,500,000 in construction funding for high energy physics projects is requested in FY 1986. The projects are:

Project Title	Project No.	FY 1986 Request	Total Estimated Cost
Tevatron I (Fermilab).................	82-E-218	$ 8,600	$ 84,000
Stanford Linear Collider..............	84-ER-133	22,900	115,400
Central Computing Upgrade (Fermilab)..	86-R-104	3,100	23,900
Accelerator Improvement Projects (AIP)	86-R-102	10,500	10,500
General Plant Projects (GPP)..........	86-R-103	10,400	10,400
		$55,500	

The construction request includes funding for completion of the Tevatron I proton-antiproton collider at Fermilab and the SLC electron-positron collider at SLAC, and for upgrading the central computing capability at Fermilab. These projects will provide experimental capabilities and research opportunities which are vital to the long-range productivity, strength and competitiveness of the United States' program. Also included are funds for accelerator improvements and modifications and general plant projects which are needed on an annual basis to maintain the efficiency, reliability and scientific effectiveness of the laboratories.

Tevatron I

The Tevatron I project at Fermilab will provide the facilities needed for a 1000 GeV on 1000 GeV proton-antiproton colliding beam capability. This will be accomplished by producing intense counter-rotating beams of protons and antiprotons in the Energy Saver superconducting magnet ring and bringing them into collision to produce about 2000 GeV of reaction energy, the highest available in the world. Specifically, the project includes: 1) additional refrigeration and radio frequency accelerating structures so that the Energy Saver ring can operate at 1000 GeV for proton-antiproton colliding beams; 2) an antiproton source; and 3) two experimental areas suitable for detectors to study the results of very high energy proton-antiproton collisions. The $8,600,000 requested in FY 1986 is the final project funding. The TEC has been increased by $1,500,000 to $84,000,000 to cover the increased costs of the magnets and experimental areas. Additional details are provided in the construction project data sheet.

Stanford Linear Collider (SLC)

The SLC project at SLAC, will provide; 1) systems for producing intense electron and positron bunches; 2) small storage ring and beam pulse compressor to increase the density of the electron and positron bunches; 3) two semicircular arcs of small aperture magnets, housed in appropriate enclosures to bring the electron and positron beams into head-on collisions; 4) special focusing systems near the beam interaction point, including the necessary housing and associated experimental hall and staging area; and 5) the instrumentation and control systems to operate these systems.

The SLC project will accelerate beams of electrons and positrons simultaneously in the linear accelerator, separate them and transport them through two semicircular arcs at the end of the linac and then bring them into head-on collision. Successful development of the SLC will provide an essential demonstration of the technical feasibility of the new linear collider concept, which is a critical step toward future cost effective extensions of electron-positron reaction energies beyond the maximum energy practical with circular colliders. In addition, when completed in 1986, the SLC will be the first electron positron colliding beam system in the world capable of achieving an energy of 100 GeV in the center-of-mass system and is expected to produce copious quantities of the recently discovered Intermediate Vector Boson (Z°), one of the carriers of the electroweak force. The detailed study of the Z° is one of the major, exciting areas of physics research indicated by present theories. The project benefits in a major way from the use of the existing 2-mile linac and supporting facilities at SLAC. The TEC for the project has been increased from $112,000,000 to $115,400,000 to reflect the impact of reduced first year funding and increased klystron costs; the estimated completion date remains the end of FY 1986. The $22,900,000 requested in FY 1986 is the final project funding. Additional details are provided in the construction project data sheet.

Fermilab Central Computing Upgrade

Significantly upgraded central computing capabilities and capacity are required at Fermilab in order to provide the data analysis capability to handle the data acquisition rates required for forefront experiments made possible by the new research facilities becoming operational with the completion of the Tevatron II construction project in FY 1985 and of the Tevatron I project in FY 1986. The primary source of this requirement is the antiproton-proton colliding beams capability of Tevatron I, which will be exploited by two major new detector facilities and by several other small colliding beams experiments. This new research program will generate unprecedented volumes of data which must be analyzed extensively by computers in order to extract physics results. Almost simultaneously, experiments using the higher energies and intensities available for the fixed-target research program as a result of the Tevatron II upgrade require larger and more complex detector apparatus which also produce much higher data rates than earlier experienced. Effective utilization of these new research facilities requires improved computing capability at Fermilab. A recent study emphasizes the urgency of upgrading the central computing capabilities in order to meet these needs.

The total estimated cost of this project is $23,900,000, with $3,100,000 requested in FY 1986. The concrete exterior structure of the building could be completed in FY 1986. Full completion of the building and acquisition of the additional central processing units, peripheral data storage devices and interfaces to user terminals would be accomplished during FY 1987 and FY 1988. Additional details on this project are provided in the construction project data sheet.

Accelerator Improvement Projects

A total of $10,500,000 is required for Accelerator Improvement Projects (AIP), to be distributed as follows: Fermilab ($5,500,000); BNL ($2,200,000); and SLAC ($2,800,000). AIP funds are required on an annual basis to provide essential modifications and upgrades of the existing accelerators and colliding beam facilities in order to maintain their scientific effectiveness and to improve their operating economy and efficiency.

It is frequently necessary to provide new or modified research capabilities on short notice in order to accommodate the particular needs of new high priority experiments. These changes are often required on a time scale much shorter than the normal two to three year Federal budget cycle. Thus AIP funds are essential to permit the rapid and flexible response essential to meet the most urgent of such needs.

There are special needs for AIP funds at Fermilab because of the very large scale and scope of the laboratory which now includes seven accelerators and pre-accelerators to achieve the Tevatron capability as well as the extended cryogenics facilities, beam extraction systems and secondary beam lines and experimental facilities. Additional details on the AIP needs at each of the three accelerator laboratories are provided in the construction project data sheet.

General Plant Projects

General Plant Projects (GPP) funds are for upgrading, modification, and improvement of the general laboratory plant at BNL, Fermilab and SLAC. GPP funds are required for projects such as utilities, support buildings, roads, shops, etc., and, although small compared to the capitalized value of the plant, are essential to keeping it in efficient operating condition. The FY 1986 request totals $10,400,000 for an approximately constant level of GPP at the following laboratories: Fermilab ($3,000,000), BNL ($5,700,000), and SLAC ($1,700,000). It is noted that at BNL the High Energy Physics Program has the responsibility to provide funding for all of the GPP needs of this multi-purpose laboratory. Additional details are provided in the construction project data sheet entitled, "General Plant Projects, Various Locations (Project No. 86-R-103)."

	FY 1984	FY 1985	FY 1986 Request
High Energy Technology			
Operating Expenses	$ 82,000	$ 90,200	$ 92,400

Progress in forefront scientific research is strongly linked to advances in technology. This occurs because the strength of the instrumentation available to researchers affects the pace at which a scientific field moves forward. Development of new and better types of instrumentation frequently requires extension of the underlying scientific principles. Research in high energy physics requires some of the most complex and technologically advanced research facilities ever built. The development of applicable supporting technology, not only in response to the needs of research but also in anticipation of them, is an essential feature of the DOE supported program in high energy physics.

The High Energy Technology subprogram has the specific goal of providing the technological base for improving the scientific effectiveness, reliability and efficiency of existing facilities and for extending the scientific capability of the experimental research program through the development, design and construction of new, advanced facilities. As a byproduct, work carried out under the high energy technology R&D subprogram frequently pushes forward or opens up new technological frontiers, thereby contributing significantly to the national technology base and to many applied needs in other areas of science and technology. In order to sustain an effective technology R&D effort that is both responsive to and stimulates the basic physics research, it is necessary to pursue a vigorous theoretical research effort into the physics and engineering principles underlying the concepts and operation of these facilities; to conduct forefront R&D in selected, promising areas of applicable technology; to develop and prove emerging ideas and concepts; and to transform these ideas and concepts into practical devices and techniques for use in physics research and elsewhere.

The High Energy Technology subprogram is subdivided into two major areas: Accelerator R&D and Experimental Facility R&D. The first is concerned with the production of particle beams and the second with the utilization of those beams for physics research. Specifically, accelerator R&D is concerned with the science and technology fundamental to charged particle accelerators, colliding beam systems, beam extraction and primary beam transport systems. Its goal is to develop new and improved concepts, techniques and devices of direct application to the acceleration, storage, and transport of particle beams to be used for probing the innermost depths of matter and energy. The end products are particle beams of higher energy, increased intensity, longer stored lifetime, greater brightness (more particles per unit transverse beam area), lower cost and greater diversity. Experimental facility R&D is concerned with the targets, secondary beam transport systems, detection apparatus, and data processing systems directly involved in the physics experiments. It focuses on developing new and improved means for generating, splitting, and transporting secondary particle beams; on inventing new types of instrumentation required for detecting and studying the characteristics of particle interactions produced in experiments; and on devising advanced processing techniques for the collection and analysis of data gathered in experiments.

While the purpose and thrust of the technology R&D subprogram is to ensure and extend the technology base vital to the progress of high energy physics research, the results of the advanced R&D effort frequently find significant application in other scientific and engineering disciplines. Thus, advances in the understanding of charged particle beam technology have contributed to the development of high powered radiofrequency tubes, electron microscopes, and x-ray sources. Standardized instrumentation systems sponsored and developed by the high energy physics program, such as CAMAC and the recently completed FASTBUS, have become national and international standards used in other research disciplines, industrial process control and artificial intelligence. Pattern recognition methods developed for bubble chamber scanning in high energy physics have been essential in the development of Computer Assisted Tomography (CAT) scanners. Superconducting magnet technology and pattern recognition methods have been applied to the new Nuclear Magnetic Resonance (NMR) devices expected to revolutionize medical diagnostics.

The high energy technology R&D activities are concentrated primarily at five DOE supported national laboratories, although a significant part is carried out by universities, industrial firms, the SSC Central Design Group and other institutions. The FY 1986 request of $92,400,000 for the High Energy Technology Subprogram includes the continuation of R&D related to SSC, a program of R&D in support of existing accelerator, colliding beam, detector and experimental facilities, and studies of very advanced concepts and techniques with potential for future applications beyond SSC. The following table summarizes the funding requests for the High Energy Technology Subprogram.

High Energy Technology	FY 1984	FY 1985	FY 1986 Request
Fermi National Accelerator Laboratory....	$ 28,394	$ 25,600*	$ 26,000*
Brookhaven National Laboratory...........	22,210	20,300*	20,800*
Stanford Linear Accelerator Center.......	15,000	15,400	15,600
Argonne National Laboratory..............	1,275	1,300	1,300
Lawrence Berkeley Laboratory.............	8,333	7,700*	8,000*
Other DOE laboratories and universities..	6,788	19,900*	20,700*
	$ 82,000	$ 90,200	$ 92,400

*Includes tentative allocation of part of the SSC funding to major participating laboratories (Fermi, BNL & LBL). All other SSC R&D funding is included within the "Other DOE Laboratories and Universities" line. Final allocation of FY 1985 and FY 1986 funding to SSC program participants will depend upon which magnet design is selected and upon recommendations of the Central Design Group for a coordinated national effort on SSC.

Fermi National Accelerator Laboratory

A total of $26,000,000 is requested for Fermilab in FY 1986 for technology R&D, compared to $25,600,000 in FY 1985. Of the FY 1986 request, $18,500,000 is for accelerator R&D and $7,500,000 is for experimental facilities R&D.

Operation of the superconducting magnet ring as a proton-antiproton collider in a totally new energy regime will begin late in FY 1986. An extensive R&D program to understand and optimize the properties and performance of the Tevatron as a storage ring will be required. Properties of the Tevatron operating with simultaneously circulating beams of protons and antiprotons will be studied with the object of improving reliability and efficiency. The operational characteristics of the antiproton source will also be studied with the aim of improving overall performance and luminosity of the collider. Prototypes of an improved large aperture lithium lens, of high frequency stochastic cooling systems, and of higher capability instrumentation and control systems will be built and tested.

R&D on advanced accelerator concepts will be carried out, including studies of the possibility of adding electron cooling to increase the brightness of the antiproton source, of laser acceleration of particles, and of a ring to decelerate antiprotons. The accelerator R&D request includes $2,800,000 for work by Fermilab related to the SSC R&D effort.

As Fermilab begins to exploit the 1000 GeV research capability made available by Tevatron II, there will be continuing work in the experimental facilities R&D program on the development of higher performance beam transport, targeting and beam splitting apparatus and on improved particle detectors for experiments to effectively utilize the higher energy fixed target research capabilities. R&D will be needed in support of colliding beam experiments and detectors, particularly of the CDF colliding beam detector to improve hardware performance, data acquisition and data reduction. Improved triggering techniques, computer software and special on-line graphics capabilities will be developed. An important component of these efforts will be R&D aimed at improvements in computer techniques and systems. More advanced software for data collection, data reduction and graphical display of results will be required.

Brookhaven National Laboratory

The FY 1986 request includes $20,800,000 for technology R&D at BNL, compared to $20,300,000 in FY 1985. This includes $17,800,000, for accelerator R&D and $3,000,000 for experimental facilities R&D.

The accelerator R&D related to the AGS will support efforts to maintain the operating effectiveness and to improve the scientific capability of the AGS. There will be a special effort directed toward achieving a major increase in AGS accelerated beam intensity, and improvements to the polarized beam capability. The accelerator R&D request also includes $5,000,000 for work by BNL related to the SSC R&D effort.

The experimental facilities R&D will focus on new detector and beam line developments aimed primarily at improving the unique capabilities at the AGS for polarized beam experiments, low energy neutrino studies and rare kaon decay processes.

Stanford Linear Accelerator Center

A total of $15,600,000 is requested in FY 1986 for Technology R&D at SLAC, compared to $15,400,000 in FY 1985. The FY 1986 request includes $8,500,000 for support of accelerator R&D and $7,100,000 for experimental facility R&D.

In FY 1986 the SLC project will be in the final year of construction. Supporting R&D will concentrate on establishing initial readiness for operation and optimizing performance. Special areas of study will include development of methods for enhancing positron beam intensity; problems of stability of high current micron-sized beam pulses in the linear accelerator during acceleration; beam transport to focus the electrons and positrons to a tiny spot and bring them into head-on collision; and methods to control the collisions of the very high intensity micron-sized electron and positron pulses.

The balance of the accelerator R&D funds will be directed toward improvements in performance, reliability, and operating efficiency of the linear accelerator and the SPEAR and PEP colliding beam devices and toward advanced concepts. There is a particular emphasis on improving the luminosity of PEP. Advanced concept R&D activities at SLAC will include development of high gradient accelerating structures, development of very high power pulsed radiofrequency sources, theoretical and experimental studies of new and advanced concepts of linear accelerator systems, development of advanced beam instrumentation and control devices, and development of special beam transport systems for micron sized beams.

Experimental facility R&D at SLAC in FY 1985 will be directed primarily toward the design of advanced detectors for future experiments at the SLC and PEP. Some R&D in support of future research using the SPEAR electron-positron storage ring, and on development of advanced detector technologies, is also included.

Lawrence Berkeley Laboratory

A total of $8,000,000 is requested in FY 1986 for technology R&D at LBL, compared to $7,700,000 in FY 1985. Of this amount, $6,200,000, is to be used to support advanced accelerator R&D, including studies of very high field superconducting magnets, collaborative studies with Fermilab and others on stochastic cooling techniques, and work on novel accelerator concepts such as the electron beat wave accelerator. Also included within this amount is work in support of aspects of the PEP and SLC facilities at SLAC and $1,400,000 for work by LBL related to the SSC R&D effort.

The experimental facilities R&D request of $1,800,000 is to support development of a hadron calorimeter for a major proton-antiproton experiment at Fermilab; studies of advanced detectors for use with linear colliders in collaboration with SLAC; work to improve the performance of experimental apparatus at SLAC/PEP and Fermilab; and long range instrumentation and detector development.

Argonne National Laboratory

A total of $1,300,000 is required for ANL in FY 1986, compared to $1,300,000 in FY 1985. Of that amount, $500,000 is for accelerator R&D and $800,000 is for experimental facilities R&D.

The high energy accelerator R&D at ANL for FY 1986 is expected to be directed primarily towards collaborative work with Fermilab on R&D for the Tevatron I proton-antiproton capability, including particle cooling techniques and beam transport. Experimental facilities R&D is expected to concentrate on research and development for new types of particle detectors; further improvements to the High Resolution Spectrometer at PEP; further developments of the CDF; and the development of new types of polarized targets.

Other DOE Laboratories and Universities

The FY 1986 funding request for R&D related to SSC is $20,000,000 (including the $9,200,000 already referenced in the Fermilab, BNL and LBL sections) the same funding level as in FY 1985. The SSC program also benefits from the results of accelerator R&D of a more general nature carried out at the national laboratories.

As discussed earlier, the Department initiated preliminary R&D related to the Superconducting Super Collider (SSC) in FY 1984. This R&D included studies of technical options and reference design studies to establish the technical feasibility and to develop credible cost and schedule estimates for the SSC. A Reference Designs Study (RDS) report was completed and reviewed in depth by the Department of Energy. DOE assigned responsibility for assisting the Department in the technical management of the SSC program during the R&D and conceptual design phase prior to construction to Universities Research Association, Inc. (URA). URA appointed a Board of Overseers and a Director for SSC activities who have established as SSC Central Design Group located at LBL to coordinate all R&D efforts on SSC.

Plans for FY 1985 include R&D and cost reduction studies on different superconducting magnet designs to determine which will yield the best SSC performance at the lowest cost; as well as R&D on other accelerator subsystems and applicable accelerator physics studies. The superconducting dipole magnet design type which appears optimum for performance and cost of the SSC will be selected by the end of FY 1985. The SSC R&D program in FY 1986 will focus on the development of a cost/performance optimized design for the selected magnet type, to develop cost effective techniques for fabrication of superconducting magnets and initial preparation for systems tests in FY 1987. Other accelerator R&D will include work on cryogenics, other technical subsystems such as vacuum, RF, power supplies, beam instrumentation and controls and accelerator physics and beam tracking studies.

It is anticipated that the SSC R&D efforts will be carried out at a variety of locations, including Fermilab, BNL, LBL, the Texas Accelerator Center, and the Central Design Group. Although a tentative partial allocation of funds to major participants has been indicated, the actual distribution and location of the work and hence the allocation of funds, will be influenced by many factors, including the magnet type selected and other actions and recommendations of the CDG for the most cost effective R&D studies.

In FY 1986, $9,900,000 is requested to support other contract research programs. These programs fund advanced technology R&D which, in general, is of a more long range nature than those discussed previously. The work under this part of the technology R&D subprogram is carried out by universities, laboratories and industry. This program presently supports contracts with about 25 institutions. The work covers a very broad spectrum of topics related to accelerators, colliding beams and detectors. Topics range from superconducting materials development to theoretical studies of non-linear dynamics. The need to develop new accelerator techniques derives from the need to optimize the cost of constructing and operating the large, modern accelerator and colliding beam facilities. While there are no known physics or technology reasons why present acceleration techniques cannot be extended to much higher energies than facilities now operating or planned, the size and associated cost of much higher energy facilities based on known technology could become prohibitive. Resources are being directed toward discovering and developing new concepts of charged particle acceleration that are more cost effective and give higher final particle energies in devices that are smaller and more energy efficient than existing ones. Representative lines of research include collective methods of particle acceleration, laser acceleration of electrons, theories of non-linear dynamics, collective effect and space charge induced phenomena, very high frequency and high power radio frequency sources, and very high field superconducting magnets. A substantial effort in this area is critical to make it possible to provide the required future HEP accelerator and experimental facility capabilities in a cost effective manner.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
HIGH ENERGY PHYSICS
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No.: 86-R-102

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 3rd Qtr. FY 1986

4. Date Construction ends: 2nd Qtr. FY 1988

5.	Previous cost Estimate:	none
	Less amount for PE&D:	none
	Net cost estimate:	none
	Date:	
6.	Current cost estimate:	$10,500
	Less amount for PE&D:	0
	Net cost estimate:	$10,500
	Date: November 1984	

7. Financial Schedule

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1986	$10,500	$10,500	$10,500	$ 5,600
1987	0	0	0	4,600
1988	0	0	0	300

8. Brief Physical Description of Project

This project provides for a variety of minor modifications, improvements and additions to the major high energy particle accelerators, colliding beam devices and experimental facilities. Funds of this type are necessary on an annual basis to maintain and improve the effectiveness of these facilities. The funds requested, which represent less than 1 percent of the present value of the government's investment in these facilities, produce a substantial return in terms of more cost effective operation and greater research productivity.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations 2. Project No.: 86-R-102

8. Brief Physical Description of Project (continued)

The following are examples of the major items of work to be performed at the various locations:

Brookhaven National Laboratory...	$2,200,000

Funds are requested for modifications, improvements and additions to the Alternating Gradient Synchrotron (AGS) and its related experimental facilities. Items planned include: a polarized proton ion source refrigeration system; modernization of the magnet and instrumentation control systems; modifications to the extraction system; a new gamma transition jump system; rf cavities; a new high harmonic rf power amplifier; a new low level rf drive system; a silicon controlled rectifier control system and additional concrete shielding.

Fermi National Accelerator Laboratory..	$5,500,000

Funds requested are for modifications, improvements and additions to the Fermilab accelerator facilities (which includes the linear accelerator, booster synchrotron, main ring, and energy saver ring) and to the switchyard, beam lines, target facilities and experimental areas.

Modifications to the accelerator facilities are expected to include: accelerator control computer improvements, including increased memory and peripherals, and more sophisticated data handling and display capabilities; improvements to the correction magnet packages to enhance beam quality and lifetimes; modifications and improvements to the low-beta magnet and power supply systems in order to achieve higher beam luminosity; improvements of the extraction and injection systems for beam transfer; improvements to superconducting dipole magnets in order to minimize magnet quenches; improvement to cryogenic system to improve control and monitoring of refrigerators and compressors and to upgrade the compressor systems; and instrumentation improvements to beam monitoring and control systems to enhance the physics output.

Modifications to the experimental facilities are expected to include: installation of additional refrigeration capacity in the experimental areas to serve the additional superconducting beam lines; upgrading of earth berms and other suitable shielding in the experimental areas to maintain radiation levels within prescribed limits as we move to higher beam energies and intensities; and new structures and modifications to buildings in experimental areas to accommodate new beamlines and experiments.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No.: 86-R-102

8. Brief Physical Description of Project (continued)

Stanford Linear Accelerator Center (SLAC).. $2,800,000

Funds are requested for modifications, improvements and additions to the SLAC linear accelerator and PEP colliding beam facilities, and to the associated experimental facilities. Items now planned for FY 1986 include: completion of the upgrade of linac energy to 50 GeV; incorporation of the remaining twenty sectors of beam position monitors into the computer control system; provide for power supply control and monitoring of the stronger quadrupole focusing magnets and steering devices; provide necessary power supplies, link boxes, cabling and other improvements which would contribute to increasing the luminosity of PEP.

9. Purpose, Justification of Need for, and Scope of Project

Accelerator improvements are essential on an annual basis to maintain the short term operating efficiency and reliability, and the research flexibility of the high energy accelerators, colliding beam systems and related experimental facilities, thereby maintaining or enhancing their level of scientific effectiveness and productivity. Research advances and facility requirements in high energy physics occur at a rapid pace; further, each research facility is a unique assemblage of very specialized, high technology components. Consequently, there is a continuing need to modify facilities, frequently on a short time scale, in response to research needs and to respond to problems that can affect the reliability, efficiency and economy of operation on a time scale shorter than the normal two-year budget cycle. The requested accelerator improvements and modifications will provide greater flexibility for experimental setups, increased performance levels, and increased serviceability, thereby decreasing facility downtime, improving the productivity, scientific effectiveness and cost effectiveness of the U.S. program in High Energy Physics.

Since needs and priorities may change, other subprojects may be substituted for those listed. Some of these will be located on non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations   2. Project No.: 86-R-102

10. Details of Cost Estimate

a. Engineering, design and inspection and component assembly and installation	$10,500
Total Estimated Cost	$10,500

The estimated costs of the programs at each laboratory are preliminary and, in general, indicate the magnitude of each program.

11. Method of Performance

Design will be primarily by contractor staff. To the extent feasible, construction and procurement will be accomplished by fixed-price subcontracts awarded on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
HIGH ENERGY PHYSICS

(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: General Plant projects, various locations

2. Project No.: 86-R-103

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 2nd Qtr. FY 1986

4. Date Construction ends: 2nd Qtr. FY 1988

5. Previous cost estimate: none
Date: none

6. Current cost estimate: $10,400
Less amount for PE&D: 0
Net cost estimate: $10,400
Date: November 1984

7. Financial Schedule

		Costs			
Fiscal Year	Obligations	FY 1984	FY 1985	FY 1986	After FY 1986
Prior Year Projects	XXXXXXX	$ 5,116	$ 1,240	$ 0	$ 0
1984	7,000	1,900	2,800	2,300	0
1985	10,200	0	2,800	4,600	2,800
1986	10,400	0	0	2,100	8,300
		$ 7,016	$ 6,840	$ 9,000	$11,100

8. Brief Physical Description of Project

These projects provide for the many miscellaneous alterations, additions, modifications, replacements, and non-major construction required at the Brookhaven National Laboratory, Fermi National Accelerator Laboratory and the Stanford Linear Accelerator Center facilities. GPP projects focus on the general laboratory facilities whereas AIP projects focus on the technical facilities.

The following are examples of the major items of work to be performed at the various locations:

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects, various locations 2. Project No.: 86-R-103

8. Brief Physical Description of Project (continued)

Brookhaven National Laboratory		$5,700
Improvements to North Area Building	$200	
Additional building for neutrino power supply and screen room	150	
Improvements to water system	900	
Construction of radiation storage building	300	
Modification to office building and upgrade of air conditioning system	150	
Improvements to assembly and storage building	450	
Construction of roads and hardstands	700	
Construction of Applied Science Whole-Building Test Facility	500	
Modifications to Medical Building	300	
Machine Shop addition	300	
Steam distribution system extension	900	
Energy measurement system	850	
Fermi National Accelerator Laboratory		$3,000
General utility improvements	390	
Cooling system improvements	825	
Experimental areas buildings and site improvements	400	
Building to house plasma cutting equipment	300	
Addition to substation	180	
Connection to new water supply	80	
Connection to sewer system	390	
Construction of heavy equipment and storage building	280	
Miscellaneous small projects	155	

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects, various locations   2. Project No.: 86-R-103

8. Brief Physical Description of Project (continued)

Stanford Linear Accelerator Center		$1,700*
Central Utility plant boiler replacement	125	
Main control building expansion addition	700	
Improvements to roadways	80	
Replacement of roofing at major buildings	145	
Replacement of critical components of the obsolete telephone system	650	

*These projects will be constructed at the Stanford Linear Accelerator Center on non-Government owned property.

9. Purpose, Justification of Need for, and Scope of Project

General plant projects are required for the general maintenance, modification and improvement of the overall laboratory plant and include minor new construction, capital alterations and additions, and improvements to buildings and utility systems. These are short-term projects whose timely accomplishment is essential for maintaining the productivity, increasing the operational cost effectiveness, and ensuring that necessary support services are available to the research program at the DOE-owned facilities. Since it is difficult to detail the most urgently needed items in advance, a continuing evaluation of requirements and priorities may result in additions, deletions, and changes to the currently planned subprojects. No significant R&D program is anticipated as a prerequisite for design and construction of the subprojects under consideration.

The funds requested for FY 1986 are estimated as follows:

Brookhaven National Laboratory	$ 5,700
Fermi National Accelerator Laboratory	3,000
Stanford Linear Accelerator Center	1,700
Total Estimated Cost	$10,400

Since needs and priorities may change, other subprojects may be substituted for those listed and some of these may be located on non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects, various locations 2. Project No.: 86-R-103

10. Details of Cost Estimate

See description, item 8. The estimated costs are preliminary and, in general, indicate the magnitude of each program. These costs include engineering, design and inspection.

11. Method of Performance

Design will be by contractor staff or on the basis of negotiated architect-engineer contracts. To the extent feasible, construction and procurement will be accomplished by firm fixed-price contracts and subcontracts on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
HIGH ENERGY PHYSICS
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Central Computing Upgrade
Fermi National Accelerator Laboratory
Batavia, Illinois

2. Project No.: 86-R-104

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 2nd Qtr. FY 1986

4. Date construction ends: 2nd Qtr. FY 1988

5. Previous cost estimate: None
Less amount for PE&D:
Net Cost estimate: None
Date: N/A

6. Current cost estimate: $23,900
Less amount for PE&D: 0
Net cost estimate: $23,900
Date: November 1984

7. Financial Schedule:

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1986	$ 23,900	$ 3,100	$ 3,100	$ 2,000
1987	0	18,000	18,000	10,000
1988	0	2,800	2,800	11,900
Total	$ 23,900	$ 23,900	$ 23,900	$ 23,900

8. Brief Physical Description of Project

The proposed project is comprised of two parts:

a) The acquisition of a major computing capacity and capability upgrade, including additional central processors, additional disc and tape storage devices, and additional interfaces to support both online user terminals and access to special purpose data processors designed for the particular requirements of high energy physics data analysis.
b) A building to house the upgraded central computing system and support personnel.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central Computing Upgrade
Fermi National Accelerator Laboratory
Batavia, Illinois

2. Project No.: 86-R-104

9. Purpose, Justification of Need for, and Scope of Project

a. Central Computing System Upgrade

Fermilab's central computing facility serves a wide variety of needs, the major ones being the analysis of data from experiments, theoretical physics calculations, accelerator design calculations, and stress analysis and magnetic field calculations used in the design of magnets and other equipment. A large central computing facility has proven itself to be the most cost effective solution to these computing needs in terms of hardware and software support, utilization of peripherals, and flexibility of computer configurations. The Fermilab central computing facility represents the only major facility of this kind which is accessible to the U.S. university participants in Fermilab experiments for the analysis of their data. At present the Fermilab central computing facility consists of three Cyber 175 computers. A lease-purchase contract for additional hardware will increase the total capacity to the equivalent of seven Cyber 175's in the period FY 1984 - FY 1986. However, a recent evaluation of the projected computing load has indicated that another increase in the computing capacity of at least a factor of five will be needed in FY 1986 - FY 1987. This increase in load is primarily due to the large additional data analysis requirements of the new colliding beam detectors for Tevatron I. The computer system upgrade requested here will meet these new needs, and will be chosen to provide the basis for growth during the remainder of the 1980's as the accelerator intensity improves and the experiments are refined.

b. Building to house upgraded Central Computer System

Since 1973 Fermilab's central computing system, tape storage, and on-line computer maintenance have been housed in Wilson Hall. Growth in subsequent years has now led to a degree of congestion which is severely affecting the efficiency and reliability of these operations. Since additional space in Wilson Hall to house additional computing hardware is unavailable, it is proposed to move these activities to a separate building specifically designed for this usage, where it will also be much easier to provide proper security for the very high value equipment which is involved.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central Computing Upgrade
Fermi National Accelerator Laboratory
Batavia, Illinois

2. Project No.: 86-R-104

10. Details of Cost Estimate

		Part A Computer Upgrade Total Cost	Part B Building Item Cost	Part B Building Total Cost
a. Engineering, design and inspection at 2.3% of Procurement and Installation (Part A) and 10.6% of construction costs (Part B)..		$ 300		$ 700
b. Construction costs............				6,800
1. Improvements to land including road, parking & landscaping...			$ 310	
2. Building..............			6,425	
a. Basic Structure..............	$3,850			
b. Mechanical..............	1,575			
c. Electrical..............	900			
d. Conveying System (Elevator)....	100			
3. Utilities..............			65	
4. Procurement..............		13,300		
5. Installation..............		200		
Subtotal..............		$13,800		7,500
c. Contingency at approximately 11% of the above cost for Part A and 15% for Part B..............		1,500		1,100
Total Project Cost by Part..............		$15,300		$ 8,600
Total Project Cost..............				$23,900

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project:	Central Computing Upgrade Fermi National Accelerator Laboratory Batavia, Illinois	2. Project No.: 86-R-104

11. Method of Performance

Design of conventional and special facilities will be by the operating contractor. To the extent feasible, construction, procurement, and installation will be accomplished by fixed-price subcontracts awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and other Related Funding Requirements

	FY 1986	FY 1987	FY 1988	Total
a. Total project costs				
1. Total facility costs				
a. Construction line item..........	$ 2,000	$10,000	$11,900	$23,900
2. Other project costs				
a. Existing equipment relocation....	0	50	50	100
Total project costs..................	$ 2,000	$10,050	$11,950	$24,000

b. Other related annual funding requirements (in FY 1986 dollars) (estimated life of project: 25 years)

1. Building maintenance and operating cost (including power)................................	$ 600
2. Programmatic operating expenses directly related to the computing facility..............	12,000
3. Capital equipment not related to construction but related to the programmatic effort in the computing facility..	1,500
4. GPP or other construction related to programmatic effort in the facility................	0
Total related annual funding requirements..	$14,100
Less: Costs associated with the operation of the existing computing facility in its present location..	- 9,900
Net incremental annual costs resulting from the construction of the new building and the operation of the upgraded computing facility.	$ 4,200

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Central Computing Upgrade
Fermi National Accelerator Laboratory
Batavia, Illinois

2. Project No.: 86-R-104

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project costs:

2. Other project costs
   a. Existing equipment relocation - the existing computing equipment presently located in Wilson Hall will be relocated to the new building upon completion of the construction, at an estimated cost of $100,000.

b. Total related funding requirements. It is estimated the facility (building) will be used 25 years for its programmatic purpose.

1. Facility operating costs. The major elements comprising the annual operating costs are electricity for lighting and air conditioning, natural gas for heating and labor for custodial and maintenance.

2. Programmatic operating expenses directly related to the facility. The estimate given here is based on the cost of the programmatic effort presently being provided for the existing facility.

3. Capital equipment not related to construction but related to the programmatic effort in the facility. This represents an appropriate funding level for central computer system enhancements.

4. GPP - No narrative required.

5. General - The net incremental costs to operate the upgraded facility are shown in item 12 at $4,200,000. The present Fermilab central computing facility is currently operational in its Wilson Hall location and would incur an annual expense of about $9,900,000 in FY 1986. These costs would continue regardless of the upgrade. The incremental costs cover items such as additional personnel, hardware and software maintenance charges, custodial, maintenance, and repair needs for the building, as well as utility costs. It has been assumed that the electrical power cost at the new facility will be partially offset by savings at Wilson Hall.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
HIGH ENERGY PHYSICS
(Tabular dollars in thousands. Narrative material in whole dollars.)

---

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

---

3. Date PE&D initiated: 2nd Qtr. FY 1980

3a. Date physical construction starts: 1st Qtr. FY 1984

4. Date Construction ends: 4th Qtr. FY 1986

5. Previous cost estimate: $114,272,000
Less amount for PE&D: 2,272,000
Net cost estimate: $112,000,000
Date: October 1983

6. Current cost estimate: $117,672,000
Less amount for PE&D: 2,272,000
Net cost estimate: $115,400,000
Date: November 1984

---

7. Financial Schedule:

Fiscal Year	Authorizations	Appropriations	Obligations	Costs
1984	$ 32,000	$ 32,000	$ 32,000	$ 23,094
1985	60,500	60,500	60,500	60,000
1986	22,900	22,900	22,900	32,306
Total	$115,400	$115,400	$115,400	$115,400

8. Brief Physical Description of Project

The SLAC Linear Collider (SLC) is a new type of electron-positron colliding beam facility which is an important step toward reducing the cost of very high energy electron-positron colliding beam devices to permit extension of the upper limit in energy above that which is at present fiscally feasible. The SLC will be constructed on non-government owned property at the Stanford Linear Accelerator Center (SLAC) which is located on Stanford University property. Its operation is based on the acceleration, in the linac, of an intense positron bunch and an intense electron bunch to energies of approximately 50 GeV each. At the end of the linac, the two bunches are injected in opposite directions into two arcs of magnets, arriving at a collision point where an effective interaction energy of approximately 100 GeV is achieved. After the collision point, the particles are disposed of and not used again. Because the beam is used only once, the magnets in the ring can have small aperture and, hence, low cost. Compared to storage rings, the single pass collider system operates at a relatively low repetition rate but makes up for the low collision frequency by the extremely high current densities which can be achieved at the collision point.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

8. Brief Physical Description of Project (continued)

The main components of the SLC are the energy upgrade of the SLAC linac; a transport system from the end of the linac to the small aperture magnet arcs; the magnet arcs themselves which includes the special focusing systems required near the interaction point; the necessary beam housing; an experimental hall and staging area; a high power positron production target at the 2/3rd point of the linac; a positron booster; a transport system from the positron target back to the injection end of the linac; a high peak current electron gun; two small storage rings, called damping rings, to reduce the emittances of the electron and positron beams by radiation damping; pulse compressors to reduce the length of the bunches in the storage rings before injection back into the linac; and the necessary instrumentation and control systems.

Since the SLC involves a new type of colliding beam system, its operation and the function of the various components are described below. A bunch of positrons containing approximately 5 x 10^{10} particles is injected into the SLAC linac. A single intense electron bunch, also of 5 x 10^{10} particles, is injected into the linac approximately 20 meters behind the positron bunch. A second electron bunch is injected behind the first intense electron pulse. This second electron bunch is used for the production of a new positron bunch. The first two bunches are accelerated in the linac to an energy of about 50 GeV. At the end of the linac a splitter takes the leading intense positron and the first electron bunch and starts them around the two magnet arcs in opposite directions. The function of the arcs is to transport the electron and positron bunches to a collision area where they collide head-on. In the collision area a collection of special lenses focuses the beams to a cross section of about 2 micron diameter at the collision point. After the beams pass through each other at the collision point they are disposed of and not used again.

The second electron bunch, which travels down the linac behind the electron and positron bunches, is deflected out of the linac at the two-thirds point and is directed onto a positron production target. Positrons from this production target are boosted to an energy of around 0.2 GeV by a short section of linac and transported by a separate magnetic-optical system back to the injector end of the main linac. There they and two new electron bunches from the electron gun/injection system are boosted to an energy of approximately 1.2 GeV and put into damping rings. In the damping rings the size of the beams decreases through synchrotron radiation damping to the appropriate value for re-injection into the main linac. The damping time for positrons is longer than the approximately 5 milliseconds between pulses of the collider system and, therefore, this ring must store two bunches simultaneously. The positron bunch which has been stored for the longest time is the one which is ejected from the damping ring and injected into the linac for the next pulse. During the time the .2 GeV positron beam is traveling back to the injector end of the linac, the high current electron gun produces two short pulses of electrons.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

8. Brief Physical Description of Project (continued)

These are timed to arrive at the injector just after the .2 GeV positron bunch. All three bunches of particles are accelerated in tandem through the first 100·M of the linac to 1.2 GeV energy. The positron bunch is switched to the positron damping ring and the two electron bunches into the electron damping ring. At the start of the next cycle one of the positron bunches and the two electron bunches are extracted from the damping rings, compressed longitudinally to a length of about 1 mm and injected into the linac. This total process is then repeated over and over again at the repetition rate of the linac.

9. Purpose, Justification of Need for, and Scope of Project

The SLC has two goals. First, it will develop and serve as a first test of a new colliding beam technique. This is a critical step toward achieving electron-positron collisions at much higher center-of-mass energies at lower cost per GeV than the technology used up to now -- that of the Colliding Beam Storage Rings (CBSR). Second, the SLC will increase the center-of-mass energy available for electron-positron experiments by a factor of about three above that now available at existing electron-positron CBSR's. The relatively low cost of the SLC, itself, is achieved by virtue of the fact that it uses the existing 2-mile linac.

The highest energy electron-positron colliding beam storage rings now in existence are the PEP Project at SLAC and PETRA at Hamburg, West Germany with center-of-mass energies of around 30-40 GeV respectively. The next step in circular colliders is the LEP machine, now being built by CERN physicists and engineers, which will achieve a maximum center-of-mass energy of about 120 GeV, initially with conventional radio frequency (RF) and subsequently as high as 240 GeV with superconducting RF. The version with conventional RF is estimated to cost about 1 billion Swiss Francs in 1981 value, not including labor costs.

In order to make use of the existing single linac at SLAC, the SLC has two arcs of magnets to guide the electron and positron bunches in different directions from the linac to the collision point. At the planned 50 GeV beam energy level the synchrotron radiation emitted in these magnets has a negligible effect on the total power required to operate the facility, while allowing it to be based on a single linac rather than two linacs. This project will not only provide critical input for a new accelerator technology, which promises to reduce costs for future generations of electron-positron machines, but will also contribute to a better understanding of the physical world through the important new experiments which it will make possible.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC) 2. Project No. 84-ER-133
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

9. Purpose, Justification of Need for, and Scope of Project (continued)

From recent research, a new theoretical concept has emerged which interprets both the weak and electromagnetic forces as different manifestations of one basic force. This concept is a form of gauge theory; the simplest form is the "standard model" of Weinberg and Salam. All of the variants of the gauge theory have one or more heavy particles which interact with the electron-positron system in the same basic way as does the ordinary zero mass photon. It is the interaction of this heavy gauge particle (Z^0) and its charged companions (W^+ and W^-) that is responsible for the properties of what is called the weak interaction. The gauge theories have had such success in explaining apparently unrelated facts that they are generally believed to be correct.

The SLC is designed to have a total energy large enough to copiously produce the neutral gauge particles, resulting in many hundreds of events per hour. The decay of these Z^0's into quarks, leptons, and perhaps other more exotic particles, will give a vast amount of information about a broad spectrum of basic physics questions ranging from the number of elementary building blocks which make up our world, and to the conditions in the early universe when it was only a few seconds old. The first evidence for the gauge particles has been found at the CERN antiproton-proton collider, but production rates are so low that experiments on this machine can give only a small fraction of the important, detailed information that can be obtained from the SLC.

Funds for detection apparatus to be used for high energy physics experiments with the SLC are included in the capital equipment budget. Equipment funds are being used to upgrade an existing detector (Mark II) previously used for lower energy experiments at PEP and for a new detector designed specifically for SLC physics. The Mark II upgrade ($11M) will be completed in FY 1986 so as to be available for physics research when SLC comes into operation early in FY 1987. Work on the new detector, called SLD, was initiated in FY 1985. SLD is expected to be completed by FY 1990, with a total DOE cost of about $40M.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

10. Details of Cost Estimate

	Item	Total Cost
A. ED&I (Excludes previously funded Plant Engineering & Design ED&I) @ 20% of construction costs, item B.		$ 16,500
B. Construction Cost:		84,000
1. Site Work, Utilities, and Structures including a) Experimental Hall; b) Collider Housing, and c) Linac-Collider Connection Tunnels.....	$ 25,500	
2. Accelerator components: a) Electron and Positron Sources; b) Energy Upgrade; c) Collider Arcs; and d) Focusing, Damping and Control Systems	58,500	
C. Standard Equipment (Cranes)		400
D. Contingency @ approximately 14% of above costs		14,500
E. Total		$115,400

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

11. Method of Performance

Design of conventional facilities will be accomplished by subcontracts. Design of technical components will be by the operating contractor (SLAC). To the extent feasible, construction procurement and installation will be accomplished by fixed-price subcontracts awarded on the basis of competitive bidding.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY 1984	FY 1985	FY 1986	Total
A. Total Project Costs:					
1. Total Facility Costs:					
(a) Construction Line Item	$ 0	$23,094	$60,000	$32,306	$115,400
(b) PE&D	2,272	0	0	0	2,272
(c) Expense Funded Equipment	0	0	0	0	0
(d) Inventories	0	0	0	0	0
Total Direct Costs	2,272	23,094	60,000	32,306	117,672
2. Other Project Costs:					
(a) R&D Necessary to Complete Construction	0	9,867	6,713	3,736	20,316
(b) Other Project Related Costs:					
(1) R&D Related Capital Equipment....	0	412	300	350	1,062
Total Other Project Funding	0	10,279	7,013	4,086	21,378
Total Project Costs (Items 1 & 2) ..	$ 2,272	$33,373	$67,013	$36,392	$139,050

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

12. Funding Schedule of Project Funding and Other Related Funding Requirements

B. Other Related Incremental Annual Costs in FY 1986 dollars (Estimated life of project: 10 years)

1. Facility operating costs (including incremental power costs)	$13,600
2. Programmatic operating expenses directly related to the facility	2,500
3. Capital equipment not related to construction but related to the programmatic effort in the facility	500
4. GPP or other construction related to programmatic effort in the facility	400
Total related incremental annual costs in FY 1986 dollars	$17,000

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

A. Total Facility

(a) Construction Line Item (no narrative required)

(b) PE&D - The SLC is a totally new kind of colliding beam system, and although the basic technology involved is well understood, the project has benefited immeasurably from Plant Engineering and Design (PE&D) funding to more firmly establish component costs and conventional facility costs and schedules. The project was provided with $300,000 of PE&D funding in FY 1980, $750,000 in FY 1981, $907,000 in FY 1982, and $315,000 in FY 1983. The FY 1980 PE&D money funded a preliminary geological study of the site, preliminary tunnel and experimental hall design, and the study of alternative site layouts. The FY 1981 PE&D funding was allocated to more detailed structural design (Title I) of the linac/collider and connecting tunnels. In June 1981, SLAC retained the services of Tudor Engineering as an A/E firm to perform Title I and Title II design on the SLC project. The FY 1982 and FY 1983 PE&D funding supported completion of Title I and partial Title II design for SLC conventional facilities.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Stanford Linear Collider (SLC)
Stanford Linear Accelerator Center (SLAC)
Stanford, CA

2. Project No. 84-ER-133

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements (continued)

(c) Expense Funded Equipment - none anticipated for this project.

(d) Inventories - no inventories are anticipated for this project.

2. Other Project Funding

(a) R&D Necessary to Complete - funds provided in High Energy Physics Research, Accelerator Research and Development.

(b) Other Related Funding Provide the capital equipment and plant funding needed in support of the R&D effort.

B. Total Related Funding Requirements:

The programmatically useful lifetime of the facility is estimated to be about 10 years.

1. Facility operating costs include the incremental costs of accelerator operations, experimental area operations, and related research and development efforts. These costs are for salaries, electric power, materials and supplies, with the dominant cost element being the electric power charges.

2. Programmatic Operating Expenses Directly Related to the Facility - this estimate is for high energy physics research to be performed by SLAC in-house physicists or physicists from the user community.

3. Capital Equipment Related to the Programmatic Effort in the Facility - this estimate is for general capital equipment needed to support research at the facility. It will provide for upgrading research detectors, data recording and analysis instrumentation and miscellaneous laboratory instruments. It does not provide for any major detection system.

4. GPP or Other Construction Related to Programmatic Effort - this estimate is a general "level of effort" which would provide for minor structures and utility extensions as well as modifications and improvements (AIP) of the facility to maintain its scientific effectiveness and productivity.

5. Other Costs - no narrative required.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
HIGH ENERGY PHYSICS
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Tevatron I, Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No.: 81-E-218

3. Date A-E work initiated: 1st Qtr. FY 1981

3a. Date physical construction starts: 3rd Qtr. FY 1982

4. Date Construction ends: 4th Qtr. FY 1986

5. Previous cost estimate: $82,500
Less amount for PE&D: 0
Net cost estimate: $82,500
Date: October 1983

6. Current cost estimate: $84,000
Less amount for PE&D: 0
Net cost estimate: $84,000
Date: October 1984

7. Financial Schedule:

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1981	$ 2,000	$ 2,000	$ 2,000	$ 1,211
1982	18,000	14,100	14,100	4,182
1983	18,000	18,000	18,000	11,845
1984	20,000	20,000	20,000	29,517
1985	21,300	21,300	21,300	24,000
1986	4,700	8,600	8,600	13,245

8. Brief Physical Description of Project

This project provides for:

1. the modification of the superconducting Tevatron accelerator ring so that it can be used as a 1 TeV proton on 1 TeV antiproton colliding-beam storage ring;
2. two experimental areas to provide facilities for simultaneous high energy physics experiments; and
3. the construction of an antiproton production, cooling and accumulation system.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Tevatron I, Fermi National Accelerator Laboratory, Batavia, Illinois
2. Project No.: 81-E-218

8. Brief Physical Description of Project (continued)

Additional satellite refrigerators are required to operate the superconducting Tevatron ring near the full energy of 1 TeV because superconductors, as they approach full magnetic field, will make the transition from the superconducting to normal state with decreasing amounts of energy deposited in them. Thus, extra cooling will prevent quenches of the superconducting ring at full energy. Additional rf cavities and other special devices are required to simultaneously accelerate and store protons in one direction and antiprotons in the opposite direction, and to optimize the collision configuration.

Two experimental areas to house high energy physics colliding beam detectors will be an integral part of the Fermilab Main Ring tunnel. The design of the experimental areas will allow the rapid efficient introduction of large detectors into the beams. To accomplish this, there will be separate detector assembly areas. The project also provides an overpass for the conventional magnet ring, to deflect it over the detector at one of the experimental areas.

The Fermilab scheme for production and collection of antiprotons uses the present accelerators, up to and including the main ring conventional magnet synchrotron, plus two additional new storage rings. The first of these is the debuncher ring, operating at about 8 GeV energy, which will have a large acceptance for antiprotons and will be used to debunch the beam as it comes from the antiproton production target. The second ring is the accumulator which will be used for cooling of the antiproton beam after it emerges from the debuncher, and for accumulating the antiprotons. The term "cooling of a particle beam" means reducing the energy spread of the beam. This cooling is particularly important for producing an accelerator quality beam from the dilute beam of secondary particles emerging from the antiproton production target. The accumulator will collect the antiprotons from about ten thousand targeting cycles. It then increases their density by stochastic cooling until the antiproton beam is intense enough to transfer into the Tevatron ring, where it will be accelerated and brought into collision with a counter-rotating proton beam. The project includes construction of the debuncher ring, the enclosures for the two rings, associated beam transport enclosures and the target station.

The research detectors required for experiments will be funded as capital equipment items. The major detector for the B-Zero Area is being fabricated over the period from FY 1981 through FY 1986. Substantial participation and financial assistance is being contributed by the Japanese, and also by Italian collaborators. The total DOE funding contribution for this detector is currently planned to be about $35,000,000. Work on a major detector for the D-Zero Area began in FY 1985. Effective analysis of the large volumes of data to be generated by the TeV I will require an upgrading of Fermilab computing capacity and capability.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Tevatron I, Fermi National Accelerator Laboratory, Batavia, Illinois   2. Project No.: 81-E-218

9. Purpose, Justification of Need for, and Scope of Project

When protons and antiprotons are stored in the superconducting Tevatron ring and brought into collision, the reaction energy available for particle production will be about 2000 GeV. This is almost 50 times greater than the reaction energy which is available at Fermilab when 1000 GeV protons strike a fixed target, although the interaction rates of the colliding beams are much lower than those of the fixed target program. This reaction energy will be sufficiently high to produce the W and Z intermediate vector bosons, which are the carriers of the weak nuclear force, and to study their properties. The data from experiments done at Fermilab and at other high energy accelerators have shown that the proton behaves as though it were made up of constituents. Past experience has clearly demonstrated that extending particle physics investigations into new, much higher reaction energies has proven to be of immense scientific value. A compelling scientific expectation is the likelihood of discovering totally unexpected phenomena at this new world record reaction energy.

10. Details of Cost Estimate

		Item Cost	Total Cost
a. Engineering, design and inspection at 17% of construction costs..			$10,100
b. Construction costs..			60,100
1. Conventional construction.....................................		$24,300	
a. Experimental areas..	$11,600		
b. Ring and beam line housing................................	12,700		
2. Special facilities..		35,800	
a. Antiproton source..	23,500		
b. Accelerator components.....................................	12,300		
c. Contingency at 20% of above costs................................			13,800
Total..			$84,000

11. Method of Performance

Design of facilities will be by the operating contractor and subcontractors as appropriate. To the extent feasible, construction and procurement will be accomplished by fixed-price contracts awarded on the basis of competitive bids.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Tevatron I, Fermi National Accelerator Laboratory, Batavia, Illinois 2. Project No.: 81-E-218

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985	FY 1986	Total
a. Total project costs:							
1. Total facility costs:							
(a) Construction line item............	$1,211	$ 4,182	$11,845	$29,517	$24,000	$13,245	$ 84,000
Total facility costs.............	$1,211	$ 4,182	$11,845	$29,517	$24,000	$13,245	$ 84,000
2. Other project costs:							
(a) Direct R&D operating costs necessary to complete construction.........	2,221	3,337	13,268	21,262	7,000	1,075	48,163
(b) Capital equipment in support of R&D	621	368	702	357	293	0	2,341
Total other project costs........	$2,842	$ 3,705	$13,970	$21,619	$ 7,293	$ 1,075	$ 50,504
Total project costs (Items 1 & 2)	$4,053	$ 7,887	$25,815	$51,136	$31,293	$14,320	$134,504

b. Total related incremental annual funding requirements (estimated life of project: 20 years)

1. Facility operating costs..	$- 3,000*
2. Programmatic operating expenses directly related to the facility..........................	2,500
3. Capital equipment not related to construction but related to the programmatic effort in the facility..	3,000
4. GPP, AIP programmatic costs..	500
Total other related annual funding requirements..	$ 3,000

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project funding:

1. Total facility costs

(a) Construction line item - explained in items 8, 9 and 10.

---

*Reference item 13.b. for explanation.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Tevatron I, Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No.: 81-E-218

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements (continued)

2. Other Project Funding:

(a) Direct R&D operating costs - Studies of stochastic cooling techniques will continue. R&D on the antiproton production target system and the accumulator ring are now in progress. R&D on other elements of the project, to optimize performance and minimize the costs of various subsystems, will continue through the late stages of construction.

(b) Other project-related costs - The items included in these costs are magnets, power supplies, electronics and other general equipment to support a.2(a) above.

b. Total related annual funding requirements - It is assumed that after Tevatron I comes into operation approximately one-half of Fermilab accelerator operations time will be for colliding beams. This means that the fixed target experimental areas will not be operating one-half of each year. During the colliding beam operating period, there will be a net reduction of power consumption at Fermilab of about 15 Megawatts compared to running full time for fixed target experiments, which corresponds to a savings of about $3,000,000 over six months at current power rates. The programmatic effort in the facility will require approximately 30 additional people, and additional material and supplies are required to effectively operate the facility. The acquisition of research detectors for Tevatron I will be made with capital equipment funds. In the future, it is anticipated that major detector upgrades will be required about every three years. GPP and AIP funds will be required as experience in operating the new antiproton source and utilizing the Tevatron as a storage ring indicates specific areas where improvements would be more beneficial.

DEPARTMENT OF ENERGY

FISCAL YEAR 1986 CONGRESSIONAL BUDGET REQUEST

GENERAL SCIENCE AND RESEARCH

NUCLEAR PHYSICS

GENERAL SCIENCE PROGRAM DIRECTION

VOLUME 4

TABLE OF CONTENTS

Nuclear Physics:

Medium Energy Nuclear Physics 88
Heavy Ion Nuclear Physics 90
Low Energy Nuclear Physics 93
Nuclear Theory 94

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET
LEAD TABLE
NUCLEAR PHYSICS
GENERAL SCIENCE AND RESEARCH - OPERATING EXPENSES
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT

(Tabular dollars in thousands. Narrative material in whole dollars)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
Nuclear Physics (ER)				
Medium Energy Nuclear Physics				
Operating Expenses ...	$ 64,634a/	$ 74,615b/	$ 74,615b/	$ 76,450
Subtotal	64,634	74,615	74,615	76,450
Heavy Ion Nuclear Physics				
Operating Expenses ...	46,773	49,448	49,448	52,650
Subtotal	46,773	49,448	49,448	52,650
Low Energy Nuclear Physics				
Operating Expenses ...	12,867	13,500	13,500	13,400
Subtotal	12,867	13,500	13,500	13,400
Nuclear Theory				
Operating Expenses ...	8,946	9,300	9,300	9,400
Subtotal	8,946	9,300	9,300	9,400
Capital Equipment	11,300	12,700	12,700	14,000
Construction	18,700c/	23,300	23,300	7,000
Total				
Operating Expenses	133,220d/	146,863	146,863	151,900
Capital Equipment	11,300	12,700	12,700	14,000
Construction	18,700	23,300	23,300	7,000
Nuclear Physics	$163,220	$182,863e/f/	$182,863e/f/	$172,900g/
Staffing Total FTE's	(Reference General Science Program Direction Decision Unit)			

Authorization: Section 209, P.L. 95-91.

---

a/ Includes $3,000,000 Defense Programs support of Clinton P. Anderson Meson Physics Facility (LAMPF) operations.

b/ Includes $3,100,000 Defense Programs support of LAMPF operations.

c/ Includes $5,000,000 transferred from High Energy Physics, ISABELLE/CBA construction project to the Tandem/AGS Heavy Ion Transfer Line Project.

d/ Does not include $780,000 transferred to the Energy Supply Research and Development Appropriation for use in accordance with the Small Business Development Act of 1982, P.L. 97-219.

e/ FY 1985 total reflects a reduction of $1,300,000 for Management Initiative Savings other than IG audits/deobligations contained in the FY 1985 President's Request.

f/ FY 1985 total reflects a reduction of $835,000 for ADP general reduction. Also reflects savings of $2,100 for Section 2901 of the Deficit Reduction Act of 1984 (P.L. 98-369).

g/ FY 1986 total reflects a reduction of $2,500,000 for FY 1986 Management Initiative Savings.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET

SUMMARY OF CHANGES
NUCLEAR PHYSICS
(In thousands of dollars)

1985 Appropriation enacted	$182,863
Built in increases and decreases	0
1986 Base	$182,863
Program increases and decreases:	
o Provide funding to maintain constant level of research, facility utilization, and instrumentation (+$7,730). Reduce overall facility utilization from 55% in FY 1985 to 45% in FY 1986; reduce overall research manpower by approximately 5%; and reduce the level of effort on Accelerator Improvement and General Plant projects by 5% (-$6,703)	+ 1,027
o Complete funding of University Accelerator Upgrade construction project in FY 1985	-11,000
o Complete funding of Tandem/AGS Heavy Ion Transfer Line construction project in FY 1985	- 5,300
o Initiate heavy ion nuclear research and accelerator operations at AGS and continue funding for initial complement of detectors	+ 3,300
o Operate new SLAC injector for nuclear research 1000 beam hours in FY 1986	+ 510
o Continue CEBAF R&D and architect/engineering activities to establish a technical base for this project so that construction could be initiated in FY 1987	+ 1,500
1986 budget request	$172,900

OVERVIEW

Introduction

The Nuclear Physics program is a comprehensive program of interdependent experimental and theoretical investigations of atomic nuclei. Long range goals are an understanding of the interactions, properties, and structures of atomic nuclei and nuclear matter at the most elementary level possible and an understanding of the fundamental forces of nature by using nuclei as a proving ground. Basic ingredients of the program are talented and imaginative scientists and a diversity of facilities to provide the variety of probes, instruments, and computational equipment needed for modern nuclear research. Approximately 80% of the total Federal support of basic nuclear research is provided through the Nuclear Physics program; almost all of the remaining 20% is provided by the National Science Foundation. Thus, the Department of Energy has a unique responsibility for this important area of basic science and its role in high technology. Long range planning, scientific community input, and coordination of Department of Energy work with National Science Foundation (NSF) activities take place through a variety of channels. The most important of these channels are external and internal review of specific research areas, frequent staff contact with counterparts at NSF, and the work of the DOE/NSF Nuclear Science Advisory Committee (NSAC).

In terms of trained manpower, new knowledge, and advanced instrumentation, the Nuclear Physics program is a central component in America's long term investment in its technological future with nuclear processes. Nuclear knowledge, techniques, instruments, and applications are an integral part of American society. These serve as the basis for our national defense strategy, for therapeutic and diagnostic medical applications, for generation of electricity with nuclear reactors (fission now and fusion in the future), and for a large and diverse array of applications in industry. The behavior of nuclei and nuclear matter determine the physical properties of our universe--from its creation from a primordial mix of energy and elementary particles, to the reactions which power our sun, to the makeup of our planet. An understanding of nuclei and nuclear phenomena is essential to any basic understanding of the world about us.

Experimental and theoretical investigations are leading us to conclude that a new level of understanding of atomic nuclei is achievable. This optimism arises from evidence that: (1) the mesons, protons, and neutrons which are inside nuclei are themselves composed of quarks and gluons and (2) quantum chromodynamics (QCD) can be developed into a theory which both describes correctly the interaction among quarks and gluons and is also an exact theory of the strong nuclear force. Study of behavior of quarks inside nuclei and of the ways in which quarks determine the makeup and properties of nuclei will have a prominent place in the FY 1986 Nuclear Physics program. Experimentally, there are two principal lines of attack: (1) scatter electrons, pi mesons, protons, and other probes from quarks bound inside nuclei to determine the distribution and motion of quarks imbedded in normal nuclear matter and to learn how these quarks reconfigure themselves in response to interactions with the various kinds of probes and (2) create regions of very high matter and energy density inside nuclei by colliding nuclei with other nuclei to determine how and if the quarks rearrange themselves and to otherwise examine how nuclear matter reacts to such extremes of stress. In nuclear theory, emphasis in FY 1986 will be on understanding the limitations of present QCD theories as exact theories of the nuclear force, on improving these theories, and on understanding the ways in which new quark configurations would signal their creation and manifest their properties.

To conduct these studies of quarks inside nuclei, a variety of probes is essential. Some of the necessary facilities are operational; for example, the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory provides intense beams of pi mesons, protons, and neutrons; the Bevalac at Lawrence Berkeley Laboratory presently accelerates nuclei of all masses up to and including uranium

(238 atomic mass units) to energies of at least one billion electron volts (GeV) per atomic mass unit; and the new off-axis injector at the Stanford Linear Accelerator Center, which became operational in FY 1985, will be an important capability for electron-nucleus scattering experiments in FY 1986. Other facilities are under construction; for example, the Tandem/AGS Heavy Ion Transfer Line construction project at Brookhaven National Laboratory will permit the Alternating Gradient Synchrotron (AGS) to accelerate nuclei with mass up to 32 atomic mass units to energies of 14 GeV per atomic mass unit. The Transfer Line construction project is scheduled for completion in FY 1986. Research and development (R&D) and architectural/engineering work in support of the Continuous Electron Beam Accelerator Facility (CEBAF) at Newport News, Virginia has been initiated.

Continuous Electron Beam Accelerator Facility (CEBAF)

Over the last decade, scientists within the basic nuclear research community identified a need for a high energy, continuous electron beam accelerator capability. By means of an ad hoc panel review chaired by Professor D. Allan Bromley of Yale University (report dated April 1983) and in formulation of the December 1983 Long Range Plan, the DOE/NSF Nuclear Science Advisory Committee has carefully examined the scientific need for CEBAF and competing alternatives and has strongly recommended its construction. NSAC's "Ad Hoc Subcommittee on a 4 GeV CW Electron Accelerator for Nuclear Physics" (report dated September 1984) reaffirmed the need and priority for the CEBAF project. Southeastern Universities Research Association is expected to serve as contractor for both construction and later operations phases of this project.

Upon completion of CEBAF, American scientists will have a unique opportunity to investigate the ways in which the quarks bound in neutrons and protons influence the makeup and behavior of nuclei, to determine how quarks interact while imbedded within nuclear matter, and to test quantum chromodynamics as the fundamental theory of the strong nuclear force. Experiments in which electrons knock protons or neutrons out of nuclei will yield information about how energy and momentum is distributed among the nucleons bound inside nuclei and will tell us about correlations among nucleons in nuclei. At the high energy limit of electron scattering, experiments are, to a good approximation, only sensitive to effects of electrons scattering from individual quarks within the nuclei. Under these circumstances, nuclei can be described as a loose collection of free quarks. At energies below 1 GeV, electron scattering from nuclei can accurately be described as electrons scattering from the protons, neutrons, and mesons known to be in nuclei. The energy capability of CEBAF would permit quantitative examination of the transition between these two diverse, but likely complementary, descriptions of nuclei. The experiments described above require coincidence measurements and thus require the unique continuous beam capabilities of CEBAF.

In FY 1986, $5,000,000 in operating expenses is requested to continue research and development and A/E activities to better define the CEBAF project's scope, schedule, and total cost. The objective of FY 1986 work is to establish a technical base for this project so that construction could be initiated in FY 1987.

Accelerator Facility Operations

Success of the Nuclear Physics program depends upon the existence and effective operation of large and complex accelerator facilities. These facilities provide the variety of projectile beams which are required for forefront nuclear research. Their capabilities determine which experiments can be performed and which cannot.

Seven existing accelerator facilities are operated by the Nuclear Physics program as national facilities. These facilities are made available to all the Nation's scientists on the basis of scientific merit and technical feasibility of proposals which are reviewed by peer groups called program advisory committees. The program advisory committee for each facility is appointed by and reports to the director of that facility. The national facilities are: the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory (LANL); the Bates Linear Accelerator Center at Massachusetts Institute of Technology (MIT); the SuperHILAC/Bevalac at Lawrence Berkeley Laboratory (LBL); the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory (ORNL); the 88-Inch Cyclotron at LBL; the Tandem/Linac Facility at Argonne National Laboratory (ANL); and the Double MP Tandem Van de Graaff facility at Brookhaven National Laboratory (BNL). The new injector at the Stanford Linear Accelerator Center (SLAC) is now operational and serves the Nation's scientists on the same basis as a national facility. Upon completion of construction in FY 1986, heavy ion beams accelerated by the AGS will also be available on a national facility basis.

Each of the national facilities accommodates major university-based user group research programs. Typically, an outside user group plans experiments and fabricates detectors and other instrumentation at the home institution, executes and partially analyzes experiments at the national facility, and completes analyses and publication of results at the home institution. Nuclear Physics directly supports 75 university-based user groups who conduct most or all of their research at these national facilities. To complement the national facilities, the Nuclear Physics program supports dedicated on-campus accelerators at Yale University, Duke University, University of Washington, and Texas A&M University. While each of the dedicated on-campus facilities has an important visitor program, these accelerators are operated principally for the research use of the host university's faculty, postdocs, and graduate students. The Duke Cyclograaff serves a consortium of three universities (Duke University, University of North Carolina, and North Carolina State University) called the Triangle Universities Nuclear Laboratory.

In FY 1986, a total of $81,260,000 of operating expenses is needed for operation of accelerator facilities. In FY 1986 the national facilities are expected to achieve an overall utilization factor of 45%, a decrease from the 55% utilization factor projected for FY 1985. Within the FY 1986 accelerator operations total, $1,450,000 is budgeted for 1000 beam hours of SLAC injector operations for nuclear research and $2,050,000 is budgeted for AGS and Transfer Line facility operations. Also, in the FY 1986 operating expenses request, $61,240,000 is planned for experimental research and $9,400,000 for theoretical research. Within the experimental research total, $260,000 is budgeted for E. O. Lawrence ($60,000) and Enrico Fermi ($200,000) Awards. Of the total FY 1986 operating expenses request, 25% is planned as direct support to universities: university-based users of American and international facilities, operation of Bates and the four dedicated on-campus accelerator facilities, research at on-campus facilities, continuation of research and development and A/E activities on the CEBAF project, and research by university theorists. University support in an amount almost equal to the direct support is also provided through the accelerator centers in the form of services in support of experiments by university scientists and delivery of particle beams to these experiments.

The Nuclear Physics program supports numerous research contracts in which there is substantial cost sharing by the universities. The universities' contributions are provided by a number of mechanisms, for example, salaries to investigators, provision of work space, local machine shop time and labor, computer time and/or equipment, etc. The Nuclear Physics program encourages such cost sharing policies to achieve maximum utilization of available Federal funds.

	FY 1984	FY 1985	FY 1986 Request
Medium Energy Nuclear Physics	$ 64,634	$ 74,615	$ 76,450

The Medium Energy Nuclear Physics subprogram supports operations and research at accelerator facilities with sufficient primary beam energy to produce pi mesons (pions) using projectiles no more massive than alpha particles. In addition, the subprogram supports nuclear physics experiments at accelerators operated by other DOE programs (e.g., High Energy Physics and Basic Energy Sciences) and at other unique domestic or foreign facilities.

Two national accelerator facilities are operated under the Medium Energy subprogram--the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory and the Bates Linear Accelerator Center at the Massachusetts Institute of Technology. Operation of the Bevalac for acceleration of hydrogen and helium nuclei is also budgeted under this subprogram. These accelerator facilities serve a nationwide community of scientists from over 100 American institutions, of which over 90% are universities. Nearly all of the "outside user" groups receive direct project support for their research activities from either the Department of Energy or the National Science Foundation. Starting in FY 1985, the accelerator at the Stanford Linear Accelerator Center (SLAC) is being operated for nuclear physics research using the new off-axis source and injector. Costs of SLAC operation of the new injector for nuclear research are supported under the Medium Energy subprogram.

Research activities planned for FY 1986 in medium energy nuclear physics range over an extremely broad selection of topics, including studies of: the fundamental symmetries of nature; distribution of electric charge and magnetic fields inside nuclei; interactions of protons, mesons, and neutrons with nuclei; neutrino oscillations and neutrino mass; interactions between nucleons; and nuclear structure.

A frequently used and productive method of improving our understanding of physical phenomena and forcing refinements of scientific theories is to perform experimental tests of the validity of fundamental hypotheses, such as the conservation of parity, time reversal invariance, and charge conjugation invariance. The invariance of physical laws under inversion of the spatial coordinates (the conservation of parity) has long been known to be violated by the weak force, which is responsible for nuclear beta decay. Medium energy experiments are determining the extent to which the force between nucleons contains a component of the weak force. Such a component would cause a violation of parity conservation in the interaction between two protons. In very difficult experiments with polarized proton beams of 15 MeV and 6000 MeV, small violations of parity conservation have been observed. However, in a recently completed experiment at LAMPF using 800 MeV polarized protons, no parity violation was seen. These intriguing results have stimulated further experimental and theoretical activity. For example, parity nonconservation due to the weak force in the scattering of electrons from nuclei will be studied in FY 1986 at the Bates accelerator using beams of polarized electrons.

The laws of physics appear to be unaltered by a transformation of all particles in a system into their antiparticles--a process known as charge conjugation. If invariance under charge conjugation is strictly obeyed, it would follow that a universe composed of antiparticles would be identical with one composed of particles. This fundamental hypothesis is being tested in a LAMPF measurement of the branching ratio for the decay of a neutral pion into three photons. Decay by this mode would violate charge conjugation invariance. At the current stage of the experiment, no violation of charge conjugation invariance has been observed. The present limit will be pushed down further by a factor of 30 (unless, of course, a violation is observed!) by the use of the new Crystal Box detector at LAMPF.

A particularly useful class of nuclear reactions may be defined as those direct reactions which are mediated by a one-body interaction between the nucleus and a short wavelength projectile. Members of this class may be considered one-body probes of nuclear structure. Elastic and inelastic scattering of electrons represents one of the most powerful of such probes. Other projectiles that are appropriate for consideration are those that are characterized by long mean free paths in the nuclear medium. This allows a relatively uniform sampling of nuclear densities throughout the nuclear volume. Much of the current research using medium energy probes is directed toward determining the degree to which pions, protons, kaons, and other hadronic projectiles also belong to this general class.

In specific situations electromagnetic information from electron scattering can specify completely the structure of the target nuclei. In these cases, the synthesis of electromagnetic data with hadronic data provides accurate information about the effective elementary interactions between hadronic projectiles and nuclei. An example is provided by recent work by Bates scientists with oxygen-16. The electron scattering and proton scattering cross sections for a variety of states are remarkably similar over a large range of momentum transfers, indicating the common character of the underlying reaction process. This is not surprising since the nuclear medium is relatively transparent to the protons of 135 MeV used in this work. In these experiments, the isoscalar transitions up to 12 MeV of excitation were studied. A particular subclass of nuclear states called "natural parity states" was investigated. Such states provide a variety of spins and inelastic densities that sample the nuclear medium at differing radii. From these experiments, accurate determinations of the density of nuclear matter have been made at different distances from the center of a nucleus to its outer surface.

This is an example of the manner in which a specific type of reaction process can be better understood by comparing results of electron and proton scattering experiments. Beyond this, the general utility of electromagnetic data to the field of nuclear reactions has long been recognized. For example, in transitions to collective states, a comparison of the hadronic and electromagnetic deformation parameters has demonstrated the one-body character of the hadronic inelastic process in the nuclear periphery, even for strongly absorbed projectiles such as pions. Electromagnetic densities have also played an important role in many efforts to determine separately the distribution of neutrons and the distribution of protons for ground and excited nuclear states.

In many current Medium Energy research activities, precise data and refined concepts point to areas whose satisfactory investigation is beyond the capability of presently available facilities. Some examples include: nucleon structure and few-body form factors; discrete states, giant resonances, and single nucleon-hole states in complex nuclei; nucleon excitation in nuclei; hypernuclei; deep inelastic scattering on few-body and complex nuclei; and tests of electroweak interaction theories. In the Medium Energy subprogram, several new approaches to these areas are being undertaken, each of which makes use of unique properties of electromagnetic probes: for example, in FY 1985 the off-axis injector at SLAC began delivery of moderate current, sharply pulsed electron beams at energies up to about 4 GeV and in FY 1986 polarized beams of tagged photons up to 300 MeV will be available at the National Synchrotron Light Source at BNL by back-scattering laser light.

Of the accelerators for which operations support is provided under Medium Energy, the largest nuclear physics program is carried out at LAMPF. The facility is centered around a linear accelerator which is capable of accelerating very intense beams of protons to 800 MeV. The ability to provide ten or more simultaneously operating beams of protons, neutrons, pions, muons, or neutrinos enables LAMPF to be a highly cost-effective basic nuclear research facility. In addition to providing beams for nuclear research, LAMPF provides beams for basic materials research and weapons development at the Weapons Neutron Research (WNR) facility.

The costs of operations at the LAMPF, Bevalac (light ion component of Bevalac operations), Bates, and SLAC (nuclear physics component) facilities require 63% ($47,990,000) of the total FY 1986 Medium Energy Nuclear Physics request. In addition to supporting the operation of the accelerators themselves, these operations costs also provide for the maintenance and operation of secondary beam lines, major spectrometer systems, and other permanently installed experimental equipment. The remaining 37% of the budget supports costs directly attributable to executing individual experiments, support of participating research scientists, continuation of R&D and A/E activities in support of the Continuous Electron Beam Accelerator Facility project, and advanced accelerator physics studies. Of the total operating expenses request in FY 1986, $21,046,000 will be for direct support of universities, including the Southeastern Universities Research Association.

The FY 1986 request for Medium Energy Nuclear Physics operating expenses is $76,450,000. Of this total, $39,765,000 is budgeted for LAMPF operations. In addition to these operations costs, $12,800,000 is required for conduct of research at LAMPF by Los Alamos scientists and by outside user groups, including university groups. The other accelerator facility entirely supported under the Medium Energy subprogram is the Bates accelerator facility. The accelerator is capable of producing electron beams of excellent quality at energies up to 750 MeV. To operate Bates in FY 1986, $5,675,000 is requested, and in addition $3,300,000 is required for the conduct of research at Bates by MIT scientists and outside user groups. A total of $7,550,000 is budgeted for continuation of R&D and A/E activities in support of the CEBAF project ($5,000,000), operation of SLAC for nuclear research ($1,450,000), and light ion operation of the Bevalac ($1,100,000). And $7,360,000 is requested for advanced accelerator R&D, Small Business Innovation Research, Fermi Awards, kaon-nucleus and photon-nucleus experiments at BNL, and user group work at accelerators whose operation is not supported by the Nuclear Physics program, e.g. Fermilab supported by the High Energy Physics program and accelerators outside the United States.

	FY 1984	FY 1985	FY 1986 Request
Heavy Ion Nuclear Physics	$ 46,773	$ 49,448	$ 52,650

The Heavy Ion Nuclear Physics subprogram supports a broad range of facilities at national laboratories and major universities. In combination, these facilities provide beams of atomic nuclei ranging in mass from lithium to uranium and in energy from a few MeV to several hundred thousand MeV. In general, each facility provides beams and experimental facilities for research groups centered both at the host institution and at other institutions. The "outside user" groups are principally based at universities. The research programs make use of unique properties of heavy ion beams or heavy ion reactions as a tool to open new research opportunities in such diverse areas as microscopic nuclear properties, macroscopic nuclear interactions, and searches for predicted exotic phases of nuclear matter. At the lowest energies and with the lightest masses, Heavy Ion nuclear research interleaves with the Low Energy Nuclear Physics subprogram. At the highest energies, many of the goals and techniques adjoin those of the Medium Energy Nuclear Physics subprogram and the High Energy Physics program.

Upon completion in FY 1986, the Tandem/AGS Heavy Ion Transfer Line construction project (84-R-123) at Brookhaven National Laboratory (BNL) will provide heavy ion beams to the Alternating Gradient Synchrotron (AGS) for acceleration to energies of 14 billion electron volts per atomic mass unit (GeV/AMU) for atomic nuclei up to mass 32 (sulfur). This capability will be unique in the world, and for the first time scientists may be able to create exotic new states of nuclear matter which have never before been observed in the laboratory. This project at Brookhaven National Laboratory represents an important initiative into the field of relativistic heavy ion collisions. In FY 1986, research and accelerations operations activities at BNL will concentrate on preparation for experiments, on the continued development of the sophisticated detectors that are necessary to exploit this exciting new field, on beam tests, and on diagnostics for this new AGS operating mode. A full ten weeks per year heavy ion nuclear research program is envisioned at the AGS beginning in FY 1987.

At LBL the Bevalac provides heavy ion beams up to 1.0 GeV/AMU (2.0 GeV/AMU for nuclei with less than 50 AMU) and can accelerate atomic nuclei of any mass up to 238 (uranium). Thus, the Bevalac and the new Tandem/AGS capabilities are complementary in both mass and energy. Increased emphasis on operations at the Bevalac with the heavier beams, including uranium, is yielding new insights into properties of relativistic heavy ion collisions. The capability to create nuclei at very high temperatures and greater than normal densities utilizing these heavy ion beams continues as an important property of this facility.

Very active research programs utilizing lower energy heavy ion beams (5-25 MeV/AMU) are supported by complementary facilities at Argonne National Laboratory, Oak Ridge National Laboratory, and Lawrence Berkeley Laboratory (ANL, ORNL, and LBL). At ANL the new ATLAS facility, scheduled for completion in FY 1985, will begin operation and provide medium mass heavy ion beams with very precise energy and excellent time profiles for use in a new generation of experiments. The Holifield Heavy Ion Research Facility at ORNL is a state-of-the-art tandem accelerator designed to achieve 25 million volts (MV) on the terminal and is well equipped with many new detection devices. Used alone or coupled with the Oak Ridge Isochronous Cyclotron, the Holifield tandem will provide precision beams and a wide variety of projectiles. The LBL 88-Inch Cyclotron presently supplies beams of the lighter heavy ions (up to 40 AMU). Upon completion in early FY 1985 of a new Electron Cyclotron Resonance (ECR) ion source, the 88-Inch Cyclotron will provide a broad selection of heavy ion species which is complementary to that of the tandem facilities because, unlike the ANL and ORNL tandem facilities, the 88-Inch Cyclotron uses positive ions throughout its acceleration cycle. Each of these national laboratory-based accelerators is operated as a national facility. Access to machine time and experimental equipment is open to all qualified scientists on the basis of proposals reviewed for scientific merit and technical feasibility.

In addition to the national laboratory accelerators, forefront facilities are also maintained at three universities--Yale University, University of Washington, and Texas A&M University. The University of Washington and Yale University facilities are being upgraded (Construction Project 84-ER-110) so that they can continue to maintain a forefront research capability in a university setting. These facilities complement the research done at the larger national laboratory facilities while at the same time providing high quality training to their graduate students. An additional upgrade is underway at Texas A&M with funds supplied by the State of Texas and the Welch Foundation.

The highest priority effort in FY 1986 in the Heavy Ion Nuclear Physics subprogram will be preparation for and initiation of heavy ion nuclear research at the AGS. The operating expenses request includes incremental funds of $2,450,000 for nuclear research with heavy ions at the AGS and for accelerator testing and facility operations. Of the Heavy Ion total request, $22,250,000 supports research activities; the remaining $30,400,000 request is for facility operations. Of the $22,250,000 request for research funds, $5,721,000 is planned as direct support to universities. Additional university support is provided through the national laboratories in the form of services in support of experiments and provision of beam time.

In FY 1986, $52,650,000 in operating expenses is requested for Heavy Ion Nuclear Physics. Of this total, $16,680,000 is requested for heavy ion operation of Bevalac; $3,550,000 is requested for operation of Brookhaven's Tandem/AGS accelerator complex; and $8,920,000 is requested for operation of ATLAS, the 88-Inch Cyclotron, and

Holifield. For heavy ion research and operations at accelerator facilities at Yale University, Texas A&M University, and the University of Washington, $2,475,000 is budgeted; $15,565,000 is planned for heavy ion research by Argonne, Brookhaven, Oak Ridge and Berkeley staff. And $5,460,000 is requested for user group research activities, Fermi Awards, and Small Business Innovation Research.

At energies of a few MeV/AMU, heavy ion reactions are dominated by fusion processes (the colliding nuclei fuse together) and peripheral reactions (the colliding nuclei sideswipe each other). Such collisions lead to highly excited projectile and target-like fragments. Heavy ion fusion provides a unique opportunity to observe the properties of equilibrated nuclear systems with large excitation energies over a wide range of angular momenta. At moderate energies, measurements of the relative decay rates of fused systems (via neutron or proton evaporation and fission decay) are being used as a "clock" to measure nuclear reaction times. Using calculated neutron emission times, the data can be used to determine decay times for the fission process and for newly discovered fission-like processes that occur in some peripheral reactions. In FY 1986, these studies will be an area of emphasis with the objective of providing a new method to measure the viscosity of nuclear matter and to address fundamental questions regarding the mechanisms for energy dissipation in heavy ion collisions.

At lower energies, near or below the Coulomb barrier, there has also been increased interest in the fusion process. Recent studies have focused on attempts to understand the extent to which the microscopic internal structure of particular nuclei determines the probability that these nuclei will fuse in a heavy ion collision. Results from these experiments are having considerable effect both by extending our understanding of the fusion process itself and by developing new techniques to use fusion reactions to produce new unstable nuclei for nuclear structure studies. Experimental studies in this area are carried on by a number of research groups using the heavy ion beams available at the ATLAS, Holifield, and the LBL SuperHILAC accelerators.

At intermediate energies of a few tens of MeV/AMU, nuclear collisions become more violent and begin to involve the emission of neutrons, protons, and even more complex bits of nuclear matter in the early stages of the reaction process. Experiments at Holifield and the Low Energy Beam Line at Bevalac are just beginning to investigate this interesting new area by studying peripheral reactions where the projectile is sometimes shattered into a few large pieces; a very active program is planned for FY 1986. A puzzling new phenomenon that has appeared in this energy regime (and also in high energy collisions of protons with nuclei) is the emission of medium mass fragments (e.g. masses of 10 to 40 AMU) at rates that are much greater than is characteristic for evaporation from equilibrated systems. Energies of these medium mass fragments are also much lower than normal for projectile shattering processes. These results are expected to provide signatures for the properties of nuclei in the transition region between a liquid-like phase which dominates the low energy regime and a gas-like phase which becomes increasingly important at high energies.

At energies of hundreds of MeV/AMU, the Bevalac is the world's only operational facility. Highlights of recent progress include the first experimental determination of the compressibility of nuclear matter by studying the emission of pions from a variety of nuclear systems and the first measurement of collective, hydrodynamical effects in heavy ion collisions. Recent experiments have used the Plastic Ball detector to make detailed measurements on most of the up to several hundred particles emitted in high energy interactions between colliding nuclei. These programs mark the beginning of quantitative studies to determine the equation of state of hot, dense nuclear matter. Research of this type is essential for providing the overall framework on which experiments at higher energies can be planned and interpreted. They provide rigorous tests of the theoretical models which are being used as a basis for predicting the exciting new properties of nuclear matter which are expected to become important at higher energies.

At energies of tens of thousands of MeV/AMU and above, theories predict that heavy ion central collisions will create an entirely new form of nuclear matter called a quark-gluon plasma. At sufficiently high temperatures and densities, it is expected that the nucleons which are the normal constituents of nuclei will dissolve into a plasma consisting of their internal substructures, the quarks and gluons. This plasma will then rapidly expand and decay into large numbers of more familiar nuclear constituents--nucleons and mesons. A vigorous theoretical effort is underway to specify the experimental signatures of these possible exotic states of nuclear matter. These theoretical studies will guide experiments in distinguishing desired events from more prolific background processes. In addition to their value to basic nuclear research, present and planned research on properties of hot, dense nuclear plasmas are becoming increasingly relevant for understanding important questions in astrophysics and cosmology. In FY 1986, it is projected that the first particle beams with energies in this region will become available at BNL (14 GeV/AMU beams of ions up to A=32 nuclei) and CERN (up to 200 GeV/AMU beams of oxygen (A=16) nuclei). The first brief experimental periods will concentrate on general surveys using modifications of existing detectors. For example, a large existing spectrometer at the AGS is being modified to accept the large multiplicity of emitted particles expected at this energy. The Plastic Ball detector at LBL is being modified and moved to CERN for use by an LBL-West German experimental team.

The accelerator facilities whose operations are supported by the Heavy Ion subprogram also provide unique capabilities for fundamental research in other fields of physics. In atomic physics the availability of uranium beams stripped of all but one or two of their atomic electrons will allow important tests of quantum electrodynamic theory using the Bevalac accelerator. An important example of the value of interdisciplinary collaborations comes from a recent joint United States - West Germany effort by nuclear scientists using unique facilities at the Heavy Ion Institute (GSI) in Darmstadt, West Germany. Here researchers have been attempting to test atomic physics predictions that low energy collisions between very heavy ions (e.g. uranium, thorium, curium) can produce for a brief instant a glob of nuclear matter with such a high electric charge that negative atomic electrons will be bound by an energy sufficient to allow the spontaneous emission of positive electrons. This process has been recently observed with the surprising result that discrete structures are superimposed on the predicted broad spectrum of energies for the positive electrons. These discrete structures have been interpreted as evidence for the existence of a giant nuclear complex with a lifetime that is orders of magnitude greater than the collision time. For these very highly charged systems, the disruptive Coulomb repulsive forces are so strong compared to attractive nuclear forces that no binding even for very short times was expected. Clearly an interesting puzzle remains for future exploration.

Heavy ion accelerator facilities also have important applications in other fields such as biomedical research and human cancer therapy. Bevalac heavy ion beams are used to evaluate the effectiveness of heavy ions in destroying human cancer cells while doing minimum damage to intervening healthy cells. This research is supported and managed by the National Cancer Institute and the Department's Nuclear Medicine Applications subprogram in the Biological and Environmental Research program. All facility operations costs of the Bevalac, including those for biomedical research, are supported by the Nuclear Physics program.

	FY 1984	FY 1985	FY 1986 Request
Low Energy Nuclear Physics................	$ 12,867	$ 13,500	$ 13,400

This subprogram emphasizes experimental investigations of nuclear structure, nuclear decay parameters, and low energy reaction mechanisms. The generally smaller scale of Low Energy research facilities and instruments make research under this subprogram especially appropriate for on-campus accelerator facilities. Of the total FY 1986 request, $4,762,000 is planned as direct support to universities.

Low Energy research on nuclear structure has been essential to development of the Interacting Boson Model (IBM) and its recent extension to odd-A nuclides in the Interacting Boson-Fermion Model (IBFM). The IBFM provides a compact and rational framework to characterize the complicated structure of odd-mass nuclides. It has also led to the intriguing possibility that there might exist symmetries in systems containing a mixture of bosons and fermions which are analogous to symmetries observed for all boson systems and for all fermion systems. On a more general basis, supersymmetry concepts, such as this one, have become of high interest in other scientific fields, in astrophysics, condensed-matter physics, and in high energy physics--where supersymmetry ideas are being invoked to try to make progress toward a grand unification of all physical forces. At present it appears that nuclear structure is a most promising area in which to search for evidence for this new fundamental concept.

Nuclei away from the line of stability play a key role in understanding systematic properties of nuclei and nuclear excitations. These nuclei can be studied over long sequences to observe the interplay of single particle and collective effects and to look for the best cases to test for supersymmetric effects. Under the Low Energy subprogram, such nuclei are provided by an isotope separator, TRISTAN, which is on-line at Brookhaven's High Flux Beam Reactor (HFBR). HFBR provides intense and unique neutron beams which are in many respects ideal for the study of nuclear structure. In addition to TRISTAN, there is a filtered beam of neutrons which is used mainly for the exploitation of the non-selective "average resonance capture" technique to obtain complete sets of nuclear levels.

In FY 1986 Low Energy Nuclear Physics research will highlight the study of the reactions of polarized beams of protons, deuterons, and neutrons (derived from reactions with polarized deuterons) with nuclei. Spearheaded by work at the Triangle Universities Nuclear Laboratory (TUNL, located at Duke University), the availability of polarized beams of neutrons in the 6 to 18 MeV energy range has made feasible new research involving the reactions of polarized beams of fast neutrons with targets of polarized nuclei. A cryogenic polarized target facility has been brought into operation at TUNL. The first measurements (on aluminum) have been made. Preliminary results indicate that the effects of the spin-spin interaction on neutron-nucleus scattering are small and that an increase in the intensity of the polarized beam would be very worthwhile. Included in the capital equipment request for FY 1986 are funds for a modern high intensity polarized-ion source for the TUNL facility. Beams of polarized neutrons are also being used at TUNL to study their scattering from unpolarized nuclei. Especially interesting results have been obtained from the scattering of 10 to 14 MeV polarized neutrons from deuterons. Theories of this simple three-nucleon system are still unable to reconcile the neutron scattering results with those obtained from proton scattering from deuterons.

The FY 1986 request for Low Energy Nuclear Physics operating expenses is $13,400,000, a decrease of $100,000 below FY 1985. Within this total for Low Energy, $4,010,000 is budgeted for light ion research and accelerator facility operations at Duke University, Yale University, Texas A&M University, and the University of Washington; $980,000 is planned for light ion facility operations of ATLAS, the 88-Inch Cyclotron, and Holifield. For light ion research by Argonne, Brookhaven, Berkeley, and Oak Ridge staff, $6,505,000 is planned in FY 1986. The remaining $1,905,000 is needed for user group research, Lawrence and Fermi Awards, and Small Business Innovation Research.

	FY 1984	FY 1985	FY 1986 Request
Nuclear Theory	$ 8,946	$ 9,300	$ 9,400

Theoretical nuclear research interprets the results of experiments in terms of fundamental theory and guides experiments by identification of those measurements which are most likely to yield definitive results. Thus, this subprogram is strongly interactive with the three (Medium Energy, Heavy Ion, and Low Energy Nuclear Physics) subprograms which are concerned with operation of facilities and execution of experiments. Major theoretical efforts are supported at the Massachusetts Institute of Technology, Argonne National Laboratory, Brookhaven National Laboratory, Los Alamos National Laboratory, Lawrence Berkeley Laboratory, and Oak Ridge National Laboratory--sites of the Nuclear Physics program's seven national accelerator facilities. In addition, the subprogram supports research at 30 universities across the Nation. In FY 1986, $5,015,000 is budgeted for direct support of theoretical nuclear research at universities.

The basic goal of nuclear theory is to understand the diverse array of nuclear species and interactions which have been observed in terms of a few simple constituents and the fundamental forces of nature. Traditionally the constituents of the many-bodied nucleus have been assumed to be the hadrons, i.e. neutrons, protons, and mesons. In recent years, elementary particle physics research has concluded that there is a substructure of the hadrons made up of quarks and gluons. It would be a major physics achievement were it possible to understand quantitatively the interactions between hadrons in terms of interactions between quarks and gluons. Most recently, theories of nucleon-nucleon interactions have evolved from simple models where quarks are treated as interacting point particles to more exact relativistic field theories. Development and implementation of these relativistic field theories for nuclear physics will be a leading effort in FY 1986.

In collisions of massive nuclei, theorists speculate there may occur phase transitions from normal nuclear matter to new forms of hot dense matter (analogous to the ice-liquid-gas transitions for water). The behavior of such transitions depends critically on the physical parameters of the models. Considerable theoretical effort is already underway by both high energy and nuclear theorists to perform lattice gauge calculations for quark-gluon plasmas to pin down the values of these parameters. In FY 1986, further effort by theorists will be undertaken to understand better the reaction mechanisms of high energy nucleus-nucleus collisions. An improved understanding is needed in order to identify those experimental signals which can be used to determine that a phase transition to the quark-gluon plasma has occurred.

When particles move at velocities comparable to the velocity of light, the motion must be treated using Einstein's theory of relativity. The conventional assumption of nuclear physics has been that the nucleons in the nucleus move at slow enough speeds that one can ignore relativity. Recent theoretical analysis of experiments using the intermediate energy proton beams at Indiana University and LAMPF now tell us that there are small relativistic components in nuclear wavefunctions which have a large effect on certain experimentally measured quantities. These new findings have led to possible answers to longstanding questions about the theoretical value of the nuclear binding energy and the alignment of the rotational spins of particles scattered from nuclei.

The FY 1986 request for Nuclear Theory operating expenses is $9,400,000, an increase of $100,000 over FY 1985. Of the $9,400,000 requested for Nuclear Theory, $5,360,000 is budgeted for theory groups located at those institutions which operate national accelerator facilities--Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory, Los Alamos National Laboratory, Massachusetts Institute of Technology, and Oak Ridge National Laboratory. For major theoretical centers at the University of Washington, Yale University, State University of New York at Stony Brook, and the University of Maryland, $2,029,000 is planned. The remaining $2,011,000 is needed for smaller university-based groups located at institutions across the United States.

	FY 1984	FY 1985	FY 1986 Request
Capital Equipment	$ 11,300	$ 12,700	$ 14,000

Capital equipment funds are needed to provide for particle detection systems, data acquisition and analysis systems, and instrumentation to improve performance of Nuclear Physics accelerators. These funds are essential for effective utilization of the national accelerator facilities operated by the Nuclear Physics program.

The pursuit of new knowledge about atomic nuclei requires a variety of probes including carefully prepared beams of protons, neutrons, antiprotons, pi mesons, kaons, photons, electrons, and massive nuclei (such as oxygen, sulfur, iron, gold, and uranium). Detection and interpretation of the results of collisions of these probes with target nuclei requires scientific instrumentation at the limits of present-day technology. In addition, the new scientific questions being asked are more discerning and thus require experiments of greater sophistication. An example of this occurs in the field of relativistic heavy ion nuclear physics, where large, fine-grained detector systems must be constructed to confront the complexity of energetic heavy ion reactions in which hundreds of fragments are produced in a single collision.

At Brookhaven National Laboratory, the Tandem/AGS Heavy Ion Transfer Line construction project (84-R-123) is creating the opportunity for an exciting experimental program with 14 GeV/AMU beams. Heavy ions as massive as sulfur (A=32) will be available in FY 1986. Central theme of this research is the search for evidence of transitions of nuclear matter to new forms such as possibly a quark-gluon plasma. Such transitions have been strongly suggested by theoretical developments in quantum chromodynamics. Since the detailed signature of transitions of nuclear matter to new forms is not known, a variety of experimental approaches must be tried. Some of these will employ existing detectors suitably modified for the study of relativistic heavy ion collisions; other experiments require the construction of new apparatus. At Brookhaven the principal effort will be to develop two complementary spectrometer systems: (1) for global event surveys, the existing Multi-Particle Spectrometer will be upgraded with new three dimensional tracking capability and novel finely-grained trigger devices to measure and identify the several hundreds of charged particles emitted from central heavy-ion collisions and (2) for detailed and precise study of selected aspects (e.g., strange particle production) of heavy-ion collisions, a new spectrometer system will be constructed. In FY 1986, a total of $3,595,000 is planned for these projects at Brookhaven National Laboratory. The requested funds are needed for continued development of these spectrometer systems and for other instrumentation necessary for startup of heavy ion nuclear research at the Alternating Gradient Synchrotron.

Two ambitious projects to construct heavy ion detector systems with unique properties are beginning at LBL and ANL. At the Lawrence Berkeley Laboratory, a new detector is planned which utilizes a time projection chamber surrounded by plastic scintillators for time-of-flight measurements. Recent results on nuclear matter equilibration, compression, and flow obtained using the streamer chamber and the Plastic Ball demonstrate the importance of such a large solid angle detector at the Bevalac. At Argonne National Laboratory, a new type of reaction product analyzer with large dynamic range, large solid angle, and capability for extremely high background reduction is planned for the ATLAS facility. This device, which exploits the unusually short beam pulses from ATLAS, will be particularly useful for studying heavy ion reaction products near or on the beam axis.

Installation of a high intensity, polarized ion source of the atomic beam type at Duke University will add an important new capability to a major university research center. The new source (Total Estimated Cost = $800,000; $300,000 in FY 1986) will enable an expanded program of study of spin-dependent interactions in nuclear physics. The higher beam currents will permit experiments to have much improved statistical accuracy and will allow the use of thinner targets resulting in better overall energy resolution.

The increasingly complex experiments at many laboratories require state-of-the-art data acquisition systems. In particular, the data acquisition and analysis systems at the Clinton P. Anderson Meson Physics Facility (LAMPF) and at the Bates Linear Accelerator Center need faster, higher capacity computers, additional fast memory and disk storage units, high-density tape drives, and higher quality text and graphics printers.

The Nuclear Physics program has responsibility for providing all of Lawrence Berkeley Laboratory's general purpose equipment. For efficient operation of the Laboratory plant and for personnel safety, obsolete equipment must be replaced on a continuing basis. In FY 1986, $800,000 is requested for all capital equipment that cannot be identified with specific programs. Some examples are: laser printer systems, an integrated site-wide communications system, graphics and phototypesetting equipment, a vision testing system, a modular semiconductor clean room facility, numerically-controlled machining and metal fabrication equipment, and a mass storage system based on optical disks to support the LBL's central computing facility.

In FY 1986, $13,200,000 in programmatic capital Equipment funds are required for the research initiatives discussed above and for maintenance of the overall productivity of the Nuclear Physics program. In addition, $800,000 is required for general purpose equipment at Lawrence Berkeley Laboratory. Of the $13,200,000 requested for programmatic capital equipment, $3,595,000 is requested for Brookhaven National primarily in support of heavy ion nuclear research at the AGS; $2,530,000 is requested for Los Alamos National Laboratory in support of LAMPF experiments and accelerator operations; and $2,825,000 is planned for research and operations at Lawrence Berkeley Laboratory (Bevalac and 88-Inch Cyclotron). The remaining $4,250,000 is budgeted for ATLAS, Bates, Holifield, SLAC, and Duke University.

	FY 1984	FY 1985	FY 1986 Request
Construction	$ 18,700	$ 23,300	$ 7,000

The total FY 1986 request for construction funds for Nuclear Physics is $7,000,000 as indicated in the table which follows:

Nuclear Physics
Summary of Construction
(Dollars in Thousands)

Project Name	Project Number	FY 1986 Request	TEC
Accelerator Improvements and Modifications...........................	86-R-204	$ 3,500	$ 3,500
General Plant Projects....................	86-R-205	3,500	3,500
Total...............................		$ 7,000	

Authorization and appropriation are not requested in FY 1986 to initiate construction of the Continuous Electron Beam Accelerator Facility (CEBAF). Research and development (R&D) and A/E activities for the CEBAF project are now underway to better define the project's scope, schedule, and total cost. This effort will continue in FY 1986 to provide the technical base for this project so that construction could be initiated in FY 1987.

Construction funds are requested in FY 1986 for Accelerator Improvements and Modifications projects and for General Plant projects. These projects are needed to maintain the scientific effectiveness, reliability, and efficiency of Nuclear Physics facilities.

Accelerator Improvements and Modifications

Accelerator facilities have continuous need during their operating life for small modifications or upgrades to enhance their performance for research use and to improve reliability and efficiency of operation. In FY 1986, a total of $3,500,000 is required for these activities under Accelerator Improvements and Modifications.

At Argonne National Laboratory, $500,000 is budgeted for a beam control system for an existing beam line in the ATLAS facility and for two general purpose beam lines for outside users. The beam control system will improve ATLAS user scientists' ability to use time-of-flight techniques for which ATLAS beams are especially well suited.

At the Lawrence Berkeley Laboratory, $1,200,000 is planned to upgrade the intensity of heavy ion beams (including uranium) at the SuperHILAC/Bevalac. In particular, the SuperHILAC's Abel injector and low energy beam transport will be upgraded for high current operation.

At Los Alamos National Laboratory, $1,000,000 is needed for improvement of LAMPF's polarized proton beams for use in nucleon-nucleon research. This FY 1986 subproject includes an optically-pumped polarized proton source, isolation transformers, injector dome modifications, a buncher-chopper system, an upgraded low energy beam transport system, and control system instrumentation.

At the Bates Linear Accelerator Center, $325,000 is requested to upgrade existing accelerator components. The accelerator's vacuum pumping system and temperature control system, which were installed when the linac was first built, have deteriorated and will be replaced with modern systems. Also, new, reliable power supplies are needed for the principal magnets in the beam recirculator.

At the Holifield Heavy Ion Research Facility, $475,000 is budgeted for a project to improve the operational reliability of the 25 million volt electrostatic accelerator. The project will increase the active insulator length of the accelerator tubes by approximately 18%. This upgrade will make operation of the accelerator more dependable and predictable.

General Plant Projects

The Construction request includes $3,500,000 for General Plant projects (GPP) at the Lawrence Berkeley Laboratory, the Bates Linear Accelerator Center at MIT, and the LAMPF facility at Los Alamos National Laboratory. At these laboratories, the Nuclear Physics program has responsibility for GPP funds which provide for minor conventional construction such as building additions, alterations, and other improvements as well as improvements to land and utility systems. A total of $2,500,000 is requested for projects at the Lawrence Berkeley Laboratory including restoration of deteriorated laboratory rooms, replacement of the emergency power systems, upgrade of buildings to improve their ability to withstand earthquakes, and electrical and mechanical utility upgrading. At the LAMPF facility, $650,000 is requested for projects which include a small building addition to provide laboratory work space for the accelerator support group and a welding shop/warehouse building. The LAMPF accelerator support and welding groups are now housed in badly over-crowded quarters. Because the workload of these groups is expected to increase in FY 1986 and beyond, the two buildings in this GPP subproject are needed to maintain satisfactory personnel safety standards at LAMPF. At Bates, $350,000 is requested for projects which include an upgrade of the primary accelerator cooling system and improvements to the gallery which houses high power radiofrequency equipment.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
NUCLEAR PHYSICS
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No. 86-R-204

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 2nd Qtr. FY 1986

4. Date construction ends: 2nd Qtr. FY 1988

5. Previous cost estimate: None
Less amount for PE&D: None
Net cost estimate: None
Date:

6. Current cost estimate: $3,500
Less amount for PE&D: 0
Net cost estimate: $3,500
Date: 5/84

7. Financial Schedule:

Fiscal Year	Authorization	Appropriations	Obligations	Costs
1986	$ 3,500	$ 3,500	$ 3,500	$ 2,200
1987	0	0	0	1,000
1988	0	0	0	300

8. Brief Physical Description of Project

This project provides for additions, modifications, and improvements to major research accelerators and ancillary experimental facilities. The requested funds are necessary to maintain and improve reliability and efficiency of operations and to provide new experimental capabilities as required for execution of planned research programs.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No. 86-R-204

8. Brief Physical Description of Project (continued)

Listed below are the laboratories and a description of each subproject:

Argonne National Laboratory (Tandem/Linac).. $ 500

A beam control system, consisting of a rebuncher, ion bunch detector, and an associated control computer, will be added to an existing beam line. Two additional general purpose beam lines will be installed.

Lawrence Berkeley Laboratory (SuperHILAC/Bevalac)... $ 1,200

Modifications to the Abel injector and its Low-Energy Beam Transport line at the SuperHILAC will include: (1) An increase in the number of quadrupole doublet lenses from four to ten to provide more focusing in the transport line. Increased beam intensity from new, high current, heavy ion sources means that space-charge defocusing forces are considerably stronger and thus improved focusing elements are needed. (2) A new isotope analysis magnet to retain momentum resolution in the presence of the increased space-charge defocusing forces. (3) Improvements to the vacuum system in the transport line to reduce beam loss. All components will be fabricated without organic material. Additional liquid nitrogen cryotraps and helium cryopumps will be installed. (4) Improvements to the injector power supply to enable it to deliver 15-mA peak current. The diodes and capacitors will be replaced, and a small bouncer supply for increased voltage stability will be added.

Los Alamos National Laboratory (Anderson Meson Physics Facility)...................................... $ 1,000

Improvements to the LAMPF polarized proton source will include: an optically-pumped polarized proton source; isolation transformers; dome modifications; a buncher-chopper system; an upgraded low-energy transport system; and control system instrumentation.

Massachusetts Institute of Technology (Bates Linear Accelerator Center) .... $ 325

Requirements include: (1) Improvements to the vacuum pumping system and temperature control system of the accelerator waveguide structure and (2) Power supplies of higher rating and reliability for the principal magnets in the beam recirculator.

Oak Ridge National Laboratory (Holifield)... $ 475

The acceleration tubes of the Holifield tandem accelerator will be extended and reconfigured so as to increase the length of active insulator by approximately 18%.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No. 86-R-204

9. Purpose, Justification of Need for, and Scope of Project

Argonne National Laboratory (Tandem/Linac)

The beam control system will improve experimenters' ability to use time-of-flight techniques for which the Argonne Tandem/Linac facility is especially well suited. The beam control system will provide computer control in the operation of an existing beam line and thus greatly enhance the efficiency of operation. The general purpose beam lines will provide places where outside users can readily install equipment brought to Argonne for experiments.

Lawrence Berkeley Laboratory (SuperHILAC/Bevalac)

First-generation experiments with relativistic, very heavy ions (gold, uranium) are well under way at the Bevalac. Demand is now being felt for the capability to perform second generation experiments that require a two orders of magnitude increase (i.e., an increase by approximately two factors of ten or an increase by 100 times) in beam intensity. One order of magnitude is being achieved by improvement of instrumentation and vacuum in the transfer line with an FY 1984 Accelerator Improvement Project. This FY 1986 subproject is an important step toward the second order of magnitude increase in beam current.

Los Alamos National Laboratory (Anderson Meson Physics Facility)

The existing polarized ion source, installed in 1976, has high polarization but limits the peak current of the polarized proton beam at LAMPF to fractions of a microampere. While this polarized beam has played a significant role in the LAMPF research program, it has become quite clear that the low intensity places an undue constraint on the productivity of the experimental program, particularly research which requires polarized neutrons. The new optically-pumped source in this subproject will increase the intensity by well over an order of magnitude (to approximately 10 microamperes peak current) while maintaining high polarization and good beam availability.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: Accelerator improvements and modifications, various locations

2. Project No. 86-R-204

9. Purpose, Justification of Need for, and Scope of Project (continued)

Massachusetts Institute of Technology (Bates Linear Accelerator Center)

Over the past ten years, the cost of reconditioning the aging Vacion pumps which pump the accelerator waveguides has quadrupled. In addition, recirculation of the beam has imposed more surface interaction with the beam causing periodic gas bursts that cannot be handled by the Vacion pumps. Whenever a Vacion pump now fails, the whole linac must be shut down. Installation of cryopumps with isolation valves will cure these problems and also provide faster pumpdown time. The temperature sensors, installed on the accelerator waveguide when the linac was first built, have deteriorated and cannot be repaired. Temperature regulation must now be done manually. Temperature sensors in the Bates linac will be replaced with modern units. Replacement of the present troublesome recirculator power supplies will provide reliable operation of the recirculator up to 1 GeV.

Oak Ridge National Laboratory (Holifield)

The purpose of the proposed project is to improve reliability of the 25 MV tandem electrostatic accelerator at the Holifield Heavy Ion Research Facility. Recent developments in arc discharge cleaning techniques for acceleration tubes manufactured by the National Electrostatics Corporation indicate that heated apertures are not required in a tube which has been arc discharge cleaned. Since the heated aperture assemblies occupy a significant fraction of the total length of the accelerator tube, removal of these elements will allow an 18% increase in active insulator length. Operation of the accelerator will be more reliable and predictable.

Since needs and priorities may change, other subprojects may be substituted for those listed and some of these may be located on non-Government owned property.

10. Details of Cost Estimate

a. Engineering, design, inspection, construction, procurement, component assembly, and installation	$ 3,500
Total Estimated Cost	$ 3,500

11. Method of Performance

Design will be by contractor staff. To the extent feasible, construction and procurement will be accomplished by fixed-price subcontractor awarded on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEETS
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
GENERAL SCIENCE AND RESEARCH
NUCLEAR PHYSICS
(Tabular dollars in thousands. Narrative material in whole dollars.)

1. Title and location of project: General plant projects
various locations

2. Project No. 86-R-205

3. Date A-E work initiated: 1st Qtr. FY 1986

3a. Date physical construction starts: 2nd Qtr. FY 1986

4. Date construction ends: 2nd Qtr. FY 1988

5. Previous cost estimate: None
Less amount for PE&D: None
Net cost estimate: None
Date:

6. Current cost estimate: $3,500
Less amount for PE&D: 0
Net cost estimate: $3,500
Date: 5/84

7. Financial Schedule

Fiscal Year	Obligations	Costs FY 1984	FY 1985	FY 1986	After FY 1986
Prior Year Projects	xxx	$ 2,004	$ 400	$ 0	$ 0
1984	$ 2,200	400	1,200	600	0
1985	3,500	0	800	1,000	1,700
1986	3,500	0	0	1,000	2,500

8. Brief Physical Description of Project

This project provides for minor new construction, other capital alterations and additions, and for improvements to land, buildings, and utility systems. Where applicable, the request also includes the cost of installed capital equipment integral to a subproject. No significant R&D program is anticipated as a prerequisite for design and construction.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General plant projects
various locations

2. Project No. 86-R-205

8. Brief Physical Description of Project (continued)

Lawrence Berkeley Laboratory .... $ 2,500

Requirements include: Second floor laboratory addition to Building 55; restoration of deteriorated laboratories and replacement of roofing in the Building 50-70 complex; structural retrofit for seismic safety in Buildings 27 and 75; and a new electrical substation in Building 50A. The Lawrence Berkeley Laboratory (Berkeley, California) is located on non-Government owned property.

Los Alamos National Laboratory (Anderson Meson Physics Facility): .... $ 650

Requirements include: (1) An accelerator maintenance building to be used as laboratory work space for the Accelerator Support Group which is now located in a much smaller and badly overcrowded building and (2) A welding shop/warehouse building to be occupied by the LAMPF Engineering Support Group whose welding activities are at present located in a crowded and inappropriate area.

Massachusetts Institute of Technology (Bates Linear Accelerator Center) .... $ 350

Requirements include: Upgrade of the accelerator cooling system by replacement of deteriorated evaporative coolers and improvement of air cooling capacity in the RF gallery which houses the new Modulator No. 6. The Bates Linear Accelerator Center (Middleton, Massachusetts) is located on non-Government owned property.

9. Purpose, Justification of Need for, and Scope of Project

Projects at the Lawrence Berkeley Laboratory, the LAMPF facility at Los Alamos National Laboratory, and at the Bates Linear Accelerator Center at the Massachusetts Institute of Technology are needed to improve efficiency and productivity of these installations and to assure continuation of safe and reliable operations for both personnel and instrumentation.

The distribution of funds requested for FY 1986 is as follows:

Lawrence Berkeley Laboratory	$ 2,500
Los Alamos National Laboratory (Anderson Meson Physics Facility)	650
Massachusetts Institute of Technology (Bates Linear Accelerator Center)	350
Total Estimated Cost	$ 3,500

Since needs and priorities may change, other subprojects may be substituted for those listed and some of these may be located on non-Government owned property.

CONSTRUCTION PROJECT DATA SHEETS

1. Title and location of project: General Plant Projects
various locations

2. Project No. 86-R-205

10. Details of Cost Estimate

See description, item 8. The estimated costs are preliminary and, in general, indicate the magnitude of each program. These costs include engineering, design, and inspection.

11. Method of Performance

Design will be on the basis of negotiated architect-engineer contracts. To the extent feasible, construction and procurement will be accomplished by firm fixed-price contracts and subcontracts on the basis of competitive bidding.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST
LEAD TABLE
GENERAL SCIENCE PROGRAM DIRECTION
General Science and Research

(Tabular dollars in thousands. Narrative material in whole dollars.)

	1984 Appropriation	1985 Appropriation	1986 Base	1986 Request
General Science Program Direction				
Operating Expenses......	$ 2,250	$ 2,175	$ 2,175	$ 2,400
Total....................	2,250	2,175	2,175	2,400
Staffing Total FTE's.....	34	39	39	39

Authorization: Section 209, P.L. 95-91.

DEPARTMENT OF ENERGY
1986 CONGRESSIONAL BUDGET REQUEST

SUMMARY OF CHANGES
GENERAL SCIENCE PROGRAM DIRECTION
(In thousands of dollars)

1985 Appropriation enacted......................................	$ 2,175
Program increases and decreases:	
o Increased personnel costs.................................	+ 305
o Impact of the Presidentially proposed reduction for the 5% decrease in salaries and benefits..........................	- 80
1986 budget request...	$ 2,400

General Science Program Direction

The FY 1986 Departmental Request for General Science Program Direction is $2,400,000, an increase of $225,000 from the FY 1985 level. These funds are required to provide for the personnel costs associated with 39 full-time equivalents in the Office of the Associate Director for High Energy and Nuclear Physics, the Division of High Energy Physics, the Division of Nuclear Physics, and associated support staff required to administer these programs. The funding increase provides for the increased personnel costs related to continuation of the FY 1985 staffing level and other increased costs associated with managing these programs, particularly in preparation for two large new facilities and for increasing international collaboration.

This staff is responsible for providing effective management, planning and direction to ensure that a viable, high quality national program of basic research and supporting advanced technology R&D is carried out in the fields of high energy physics and nuclear physics. To carry out these responsibilities, the staffs assess the basic research needs in these areas with advice from the appropriate advisory committees, the High Energy Physics Advisory Panel (HEPAP) and the DOE/NSF Nuclear Science Advisory Committee (NSAC). The DOE staff participates actively in both HEPAP and NSAC meetings and special subpanel studies and provides administrative support for their operation. (NOTE: This responsibility is rotated between NSF and DOE. DOE staff will have administrative responsibility for NSAC again in FY 1986 and FY 1987.) The staff develops and coordinates with appropriate agency and external communities a coherent policy and long-range plan for support of balanced national programs in high energy and nuclear physics; develops budget requests and justification for funding to implement program plans; optimizes the allocation of resources to the laboratories and universities supported by the Department to achieve maximum research productivity, cost effectiveness and efficiency of operation; provides technical oversight for high energy and nuclear physics research programs of 15 major laboratories and about 200 university contractors; and provides technical and project management oversight for 5 major construction projects. Effective oversight of high energy and nuclear physics activities requires staff participation in formal annual on-site program reviews of contractors; semiannual on-site reviews of major projects; meetings of laboratory program advisory committees; special facility and research planning meetings; and regional, national, and international research meetings and technical workshops. The staff also participates extensively in international cooperative efforts, which involve the development and management of activities under three formal agreements for cooperation, including participation of U.S. scientists both in experiments at foreign facilities with unique capabilities not available in the U.S. and in conferences and workshops abroad.

The High Energy Physics staff oversees the operation of three large, complex high energy accelerator centers at BNL, Fermilab, and SLAC which are used by qualified physicists from throughout the Nation. The staff will provide technical oversight for two major ongoing construction projects, the Tevatron I ($84,000,000) at Fermi with scheduled completion late in FY 1986 and the Stanford Linear Collider (SLC) ($115,400,000) at SLAC with scheduled completion late in FY 1986. The upgrade of Fermilab's central computing capability necessary to complete the Tevatron projects, will begin in FY 1986. The staff will provide technical oversight for the operation of existing facilities and preparation for operation of the new capabilities becoming available with the completion of the Tevatron and SLC projects. The staff manages over 100 university research tasks. It also oversees an extensive program in advanced technology R&D including efforts in support of ongoing construction projects, efforts related to enhancing scientific capability and operating effectiveness of existing facilities, advanced accelerator R&D whose goal is to assess technical options and develop cost optimized designs and fabrication techniques for the Superconducting Super Collider (SSC), and studies of advanced concepts. Effective management of an effort of the magnitude and complexity of SSC will require close attention by the High Energy Physics staff to ensure proper DOE oversight of the technical and management performance by the contractor.

Success of the Nuclear Physics program depends upon effective operation of seven large and complex national accelerator facilities. Nuclear Physics staff will oversee high priority, new research capabilities at BNL (Tandem/AGS Heavy Ion Transfer Line), SLAC (off-axis injector), and ANL (ATLAS Construction Project). This staff will continue to oversee the University Accelerator Upgrade Project at the University of Washington and Yale University. In addition, this staff will be responsible for managing R&D associated with the proposed Continuous Electron Beam Accelerator Facility to be located at Newport News, Virginia. This project will be built by a consortium of universities unfamiliar with Departmental construction procedures. Extraordinary staff work will be required for the success of this project. The staff will determine project cost estimates and schedules and conduct monthly project reviews. As the electron scattering programs around CEBAF develop and as heavy ion capabilities at BNL commence operation, Nuclear Physics staff will need to develop and manage a university-based (approximately 20 university contracts) user program and a theory program supporting them. Theoretical work will include controlling use of time to be made available for theory calculations on a large computer, including review of proposals at LANL and LLNL, and evaluation of the needs of theorists for smaller on-site computers. The Nuclear Physics staff manages more than 100 university research tasks covering an exceedingly broad and diverse range of activities. The Nuclear Physics program staff also manages the Nuclear Data activity which is budgeted under Basic Energy Sciences.

The High Energy and Nuclear Physics staff also manages the Heavy Ion Fusion Accelerator Research program budgeted under Basic Energy Sciences. This program will develop heavy ion accelerator technology and perform appropriate ion-beam experiments to the point where an adequate data base will exist for future decision-making. FY 1985 to FY 1987 activities involve overall policy and program planning and management, as well as review and evaluation of the first stage of research and development activities carried out under laboratory projects. FY 1986 workload will include increased planning and evaluation activities associated with expanded equipment needs for the innovative multiple beam experiment, and for the transition from the multiple beam experiment to the requirement in future years for a new facility called the High Temperature Experiment (HTE). The HTE will require considerable staff effort in conceptual design review, site selection and criteria definition. It also requires new systems studies and increasing proposal evaluation activities. Monitoring of foreign activity, particularly in West Germany and Japan, will increase; and management of a joint collaborative experiment at the Rutherford-Appleton Laboratory in England has begun. These activities are in addition to the normal day-to-day management responsibility which includes site visits to evaluate progress toward development of heavy ion accelerator technology, responding to inquiries and attending appropriate national and international conferences.

○